DESIGN AND ENGINEERING OF AN ENERGY HARVESTING SYSTEM FOR SMART CLOTHING

MSC. INTEGRATED PRODUCT DESIGN

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PREFACE

Here starts the report about the “design and engineering of an energy harvesting system for smart clothing”. In this report all processes are described which eventually lead to the final product: the Solar collar.
The project is divided in eight chapters which each have their own focus. Within these chapters subchapters are structurally used to cover as much as possible.

The chapters one and two are the chapters that cover quite some research from literature and with that this project’s frameworks are defined. These chapters are interesting for all readers as this also covers more general information about the development of smart clothing.

Within chapter three and four existing mechanisms and techniques are researched. By using these reference points design decisions could be made. By doing so the wheel did not have to be rediscovered and the focus could be on the improvement.

Chapters five and six the process of the design of both the functionality and aesthetic was explained. Within these two chapters the diverging and converging thinking process is clear and shows how the product was shaped to the final product.

The last two chapters show how the concept was validated and new criteria have been set up according to the findings of tests.

I hope you enjoy my most exciting project which will also mark the end of my time as a student. Thank you

- Vinay Gaya

TABLE OF CONTENTS

1. INTRODUCTION

Technological advancements are happening all around us. These advancements are initiated to better the operations or the impact of those industries in which these advancements are integrated. One of these industries that this project is going to focus on is the fashion industry which is one of the most polluting industries currently. This industry is more polluting than all the international flights and maritime shipping combined (Business insider, 2019).

Over the years other innovations in this industry have been made which broadened the possibilities to produce clothing for a lower price which eventually led to fast fashion. The rise of polyester was thought to be something good as this was taking some pressure off the production of cotton and other more costly materials. Durability was also one of the qualities of this new material. Relatively new research has identified a downside of this material. It was proven that every washing session of polyester clothing causes microplastics that end up in our ocean (Hernandez, Nowack, & Mitrano, 2017).

To improve the current impact of the fashion industry a new concept could be used. One of these concepts is smart clothing. This concept offers potential in terms of usability and even in lowering the ecological impact of the current fashion industry. For this reason this research is going to focus on the possibilities to lower the impact of the fashion industry by searching possibilities for energy harvesting through human body movement over the day. Using clothing as a carrier of these energy harvesting components could add value to the current development of smart clothing and the possible features.

1.1 SMART CLOTHING

What exactly is “smart clothing”? “Smart clothing” is one application of intelligent textiles. This term refers to all clothes made with intelligent textiles or in which they are applied (Mattila, Mäkinen, Talvenmaa, 2002). “Intelligent textiles” or “Smart materials” are defined as the following: “Smart materials, called also intelligent or responsive materials, are designed materials that have one or more properties that can be significantly changed in a controlled fashion by external stimuli, such as stress, moisture, electric or magnetic fields, light, temperature, pH, or chemical compounds. Smart materials are the basis of many applications, including sensors and actuators, or artificial muscles, particularly as electroactive polymers (EAPs)” (Badami & Ahuja, 2014)

Another more simpler definition is given as the concept of infusing technology with clothing and thus creating a wearable computing system (Mann, 1996, p. 23). The concept of smart clothing is still open for various interpretations as the development is still ongoing. The capabilities of smart clothing are dependent on the type of elements that will be embedded in that specific piece of garment. These elements can be the type of smart materials, the type of electrical components and the composition of these elements.

1.2 ASSIGNMENT

With the development of these smart clothing the energy demand might increase as this can also be an efficient stimuli for smart clothing to change. Another fact is that the fashion industry is one of the most polluting industries (Business insider, 2019). Using these two statements as the base for this final project would offer huge possibilities for improvement of these situations. For this reason the aim for this project would be to improve the current way of operations. To make the goals more clear the sustainable development goals can be used which the United Nations have established which should lead to “ a better and more sustainable future for all” (United Nations, n.d.) . This project will take into account goal 7 (Affordable and clean energy) and goal 12 (Responsible consumption and production).

The assignment for this project is to create a possibility to generate energy from integrating energy generating elements in which the carrier of these energy generating systems will be clothing. The challenge lies in evaluating the different possibilities of the energy harvesting elements on efficiency, feasibility, desirability, viability and sustainability. By doing so a well considered end product will be the result of this project and a certain morphological chart of possibilities will be available for potential further projects.

Evaluating with which of the energy harvesting methods the system should work with should be considered as well. No energy is “free” so the energy that is going to be harvested needs to come from a certain place on the piece of clothing. The location of these energy harvesting modules should be evaluated too as the location should not limit the mobility of the user. The location also plays a significant role in being able to generate a useful amount of energy for the capabilities of smart clothing or small wearables like smartwatches or biosensors. After this evaluation a decision should be made on how to embed this energy harvesting technology in or on textile. The embedding in the textile should be part of a system.

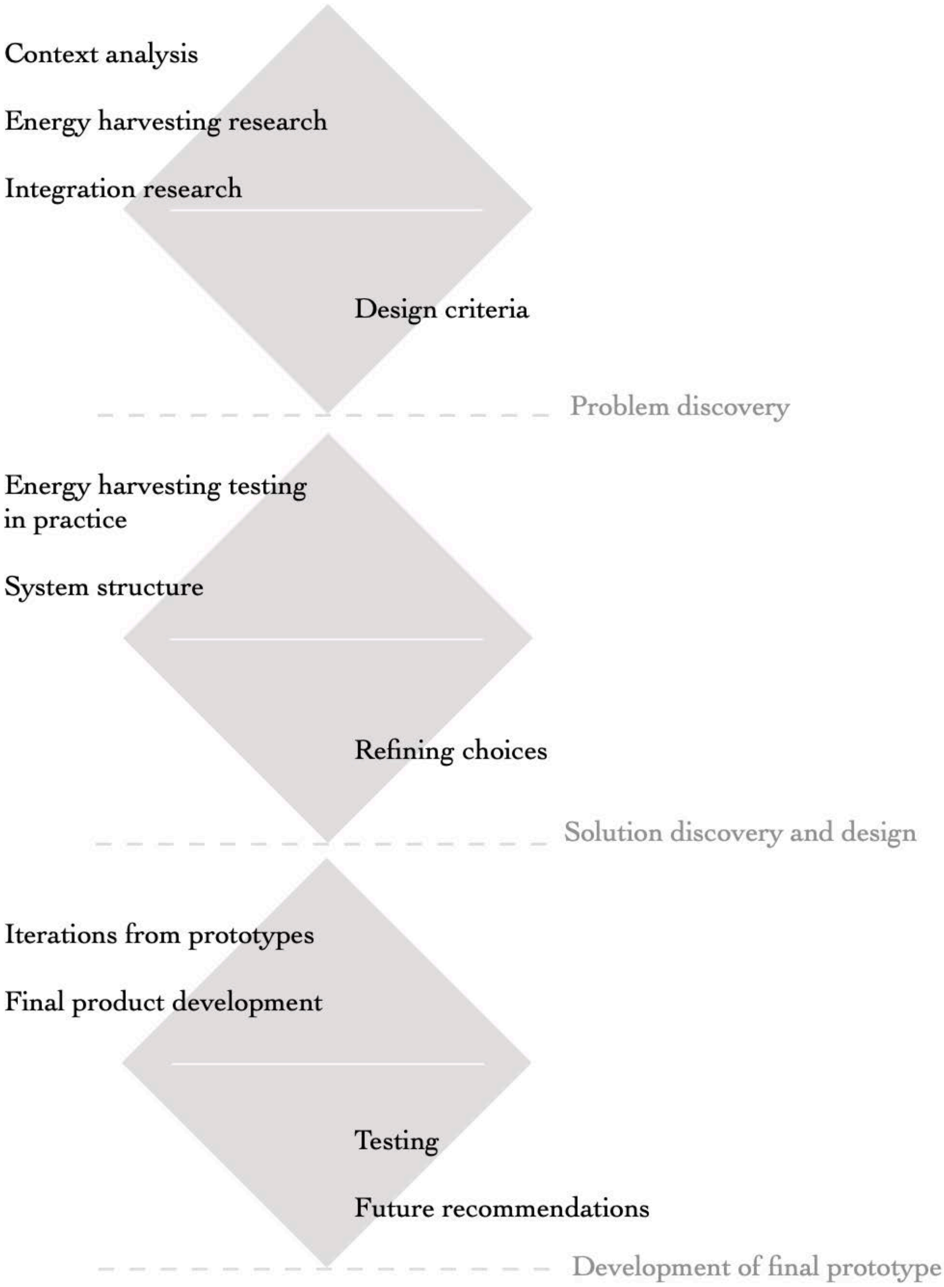


Figure 1: The triple diamond design model highlighting the different phases of this project.

PROBLEM DEFINITION

For this project, no external client like a business is chosen. Clients are often focused on the commercial aspect so the project and want the end product to be of use for their portfolio. With this project, I aim to focus more on the potential for future developments of the integration of technology with (smart) clothing thus meaning that the focus of this project could be more on the conceptual element.

Creating a solution for energy harvesting in smart clothing is the main goal. Important is the comfortability of embedding the energy harvesting elements into clothing and the reliability of this system. Certain levels of elaborating this project have been set in order to set a goal for the coming period of working on the thesis.

LEVEL 1

The system should be able to withstand normal human movements like walking and sitting.

LEVEL 2

The system embodiment aesthetics should be fitting to different styles of clothing and should have a good user experience considering comfort.

LEVEL 3

The system should be modular such that components can easily be interchanged.

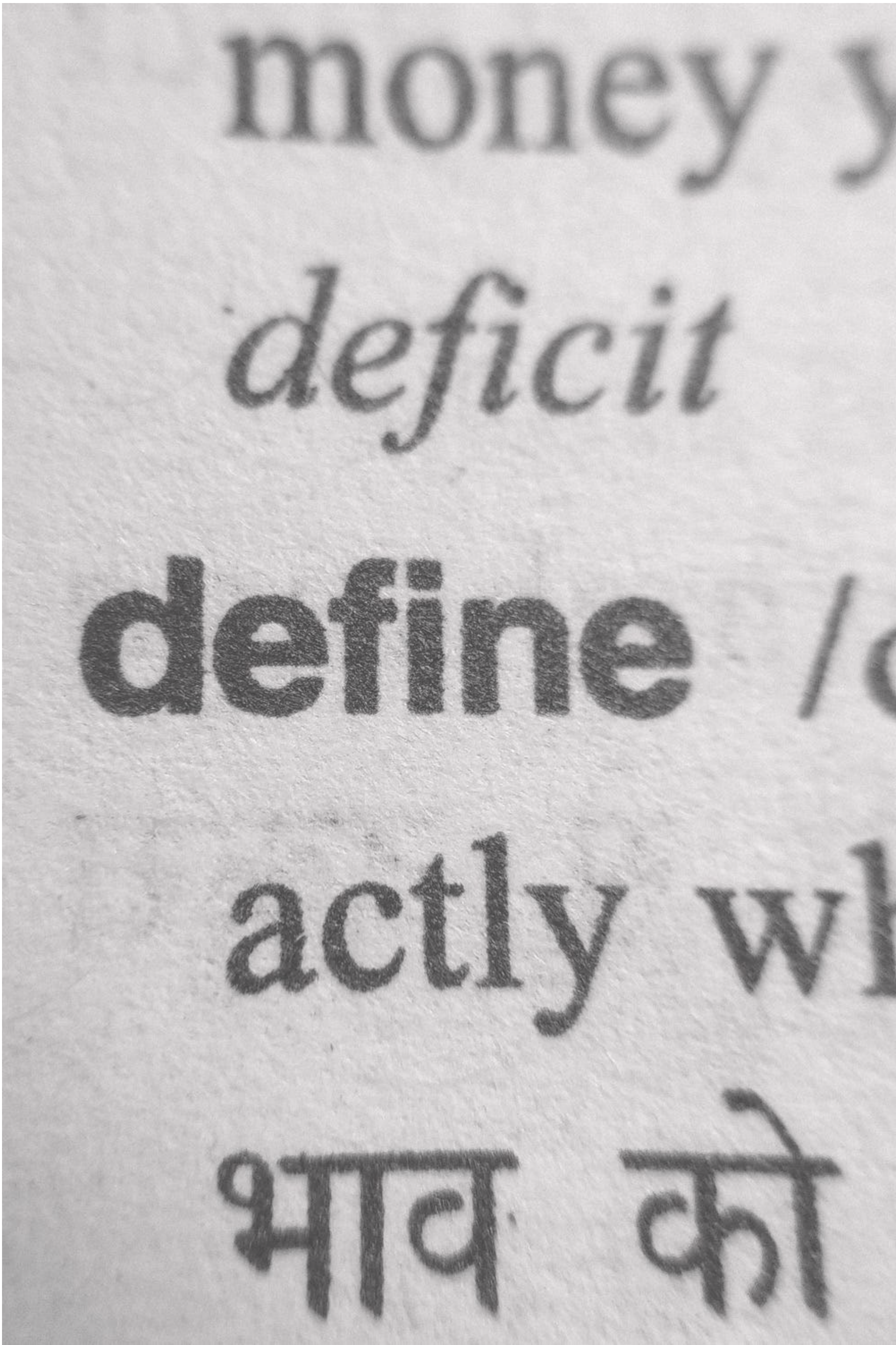
At least level one should be achieved in which a working model that withstands normal human movements should be designed.

Level two is important in order to evoke the desirability for smart clothing to the masses. A study has shown that fashion's primary consideration is a garment's aesthetics and the message it communicates rather than its function (Seymour, 2011). Therefore, to make smart clothing desirable for the masses the integration of electronics into clothing should not hinder the aesthetics of the piece of clothing itself.

Level three is to aim for a future of products in which the electrical waste is minimized. By having modular products components that fail over time can be replaced instead of having to replace the entire product.

2. CONTEXT

Before the integration of the energy harvesting components in clothing can be realized an analysis should be made. This analysis help to further create a design framework. These can consist of defining the target group and research criteria which the solution should meet.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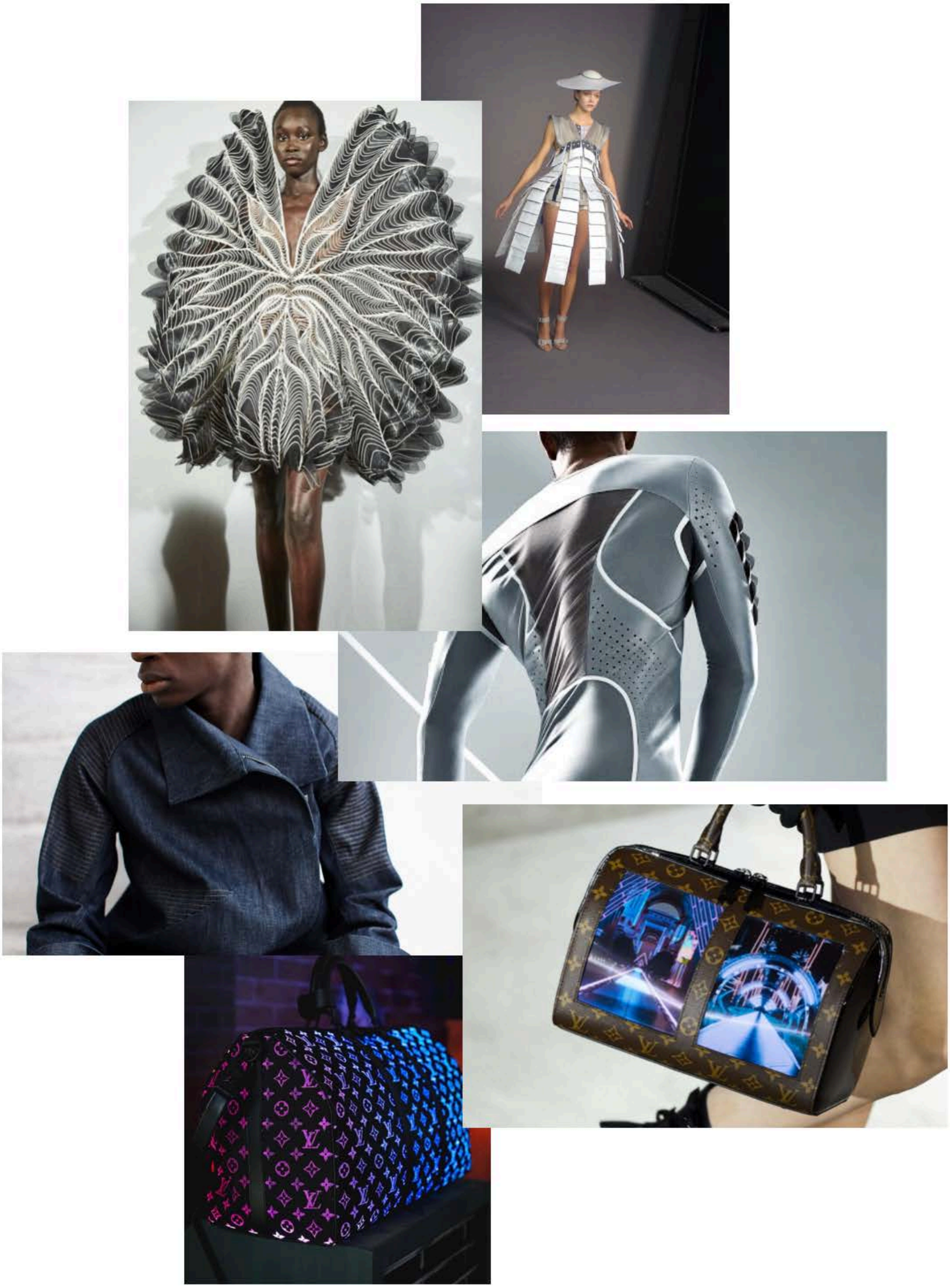
2.1 FUTURE OF CLOTHING



This thesis is going to be focused on the possibility to generate energy through clothing. More products are being dependent on energy. The development of smart clothing also can be seen as one of the examples of this statement. At Louis Vuitton's cruise 2020 runway show in New York, a new bag was shown in which OLED screens were embedded into bags. Something similar has been done to showcase their sneakers on the same runway. These were still prototypes but showcase the potential of integrating electronics with fashion for their aesthetic. Apart from aesthetics, the development of clothing has more possibilities. As smart clothing can also be dependent on external stimuli like an electrical current the question to make the production of clothing energy- neutral or negative may be worth investigating.

Given the example of Louis Vuitton's 2020 collection with integrated OLED screen shows how future clothing can be dependent on energy too. The generated energy could be used for the functionalities of these futuristic clothing rather than having to charge batteries for this too. One question might be: how much energy is needed. Preferably as much as possible to make clothing energy negative. For this project, a more feasible goal is set in which the amount of harvested energy should be sufficient to be used to charge a small portable device. This is further defined in the following chapter in which the target audience for this project is mentioned.

In order to get familiar with the quantities of energy for this thesis the amount of energy needed for wearable consumer products is given as a reference. The unit to indicate the amount of energy that is needed will be done in the same way that is done by MacKay in his book about sustainable energy (2009). The energy needed for something as small as a smartwatch is relatively low. For standardization, we focus on the needed energy of the Apple watch as this is the most popular smartwatch in the market according to analyst firm Counterpoint research (2020). The battery within the apple watch mentioned the capacity of the battery to be 0,93 Wh. With a full charge of the watch, it will thus need no more than 1 W. To charge an iPhone from zero to a hundred percent the 10,53 Wh is needed.

2.2 TARGET GROUP

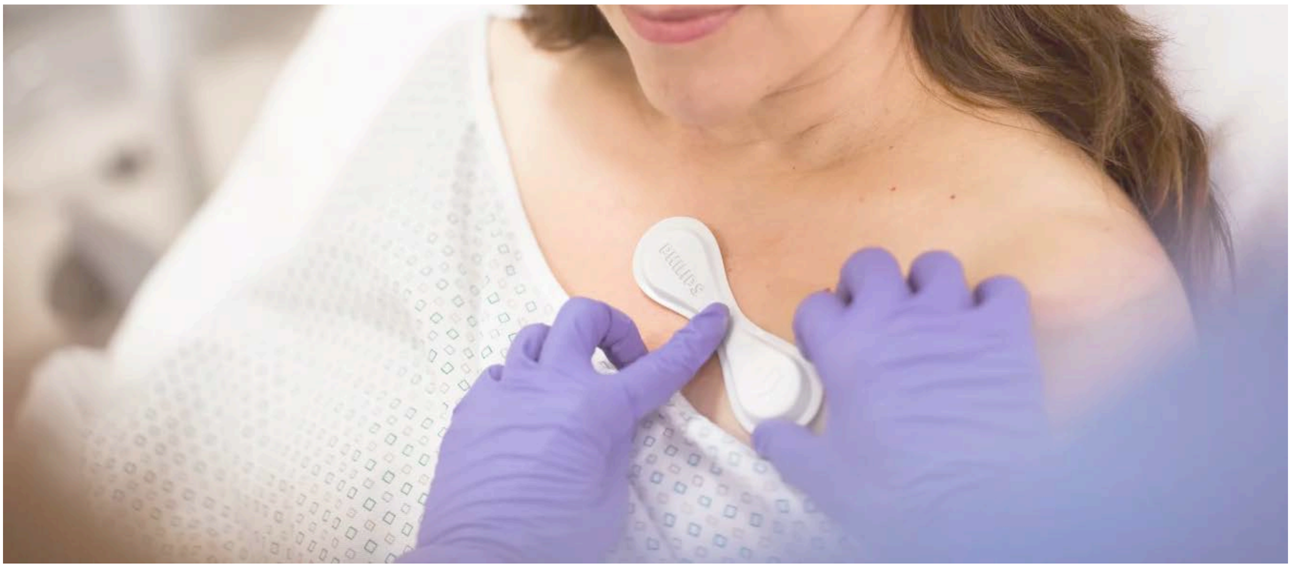


Figure 2: The Philips biosensor (Philips, n.d.)

In order to create more context for this thesis’s purpose a target group is defined. The energy harvesting elements that are to be designed could be made specially to cater to the target group’s needs. Doing so makes this the base of this technology's application.

The example of Hennie as a persona is an embodiment of this project’s target group. Hennie, is an elderly person, lives on her own after her husband has died. Now that she gets older she has trouble with maintaining her balance. Her (grand)children had to help her 2 times in the last half-year because she had fallen at home and couldn’t handle the pain. Hennie also has to keep her blood pressure in check as this can affect her heart and cause other complications.

Hennie uses a biosensor which monitors her state of health and communicates this data to a receiver that is connected to wifi. Hennie’s children can so get notifications when the biosensor senses if she has fallen or there is an inconsistency occurring in her heart rate.

NAME:	HENNIE
AGE:	76
FAMILY:	WIDOWER AND HAS 3 KIDS AND 5 GRANDKIDS
LOCATION:	THE NETHERLANDS

BIOSENSORS

The rise of IoT made way for the innovation of traditional products or ways of operating. In the medical sector, these innovations could save lives. Currently, many businesses focus on this market like tech giant Apple with the Apple watch series 6 integrating a blood oxygen meter, ECG, and fall detection which were mentioned to be particularly handy for the elderly. Especially during the current circumstances with a pandemic taking place.

Not only Apple tries to add value to this market. Other businesses and instances like Philips, Samsung, and various institutes like the California Institute of Technology are adding to this market too. The products that are developed usually consist of sensors tracking the heart rate, R-Rinterval, blood glucose levels, blood oxygen levels, blood pressure, body temperature, body posture, step count, respiratory rate, and/or fall detection. According to Business Insider’s article on medical monitoring devices and wearable health technology (2020) this market brought more companies to make these technologies more commercial. The effect is that many businesses make these sensors into wearables. One such example is business insider's winner of the best wearable at the 2019 Consumer Electronics Show: they made the world's first analog watch with an integrated electrocardiogram (ECG).

While many of these sensors are going to be implemented in everyday products like the smartwatch, other institutes and businesses also try to keep these sensing modules focussed on their medical purpose. Philips’ wearable biosensor is one of the modules that packs 8 sensors and is marketed to be used professionally in hospitals. The sensors would make it more efficient to keep track of the patient’s state of being. This makes it possible for others to act quickly in case of an emergency.

The Philips biosensor is one of the few sensors of which the energy specifications are mentioned as many other wearables monitoring products are not commercially available yet.

The Philips module lasts 4 days on a full zinc-air battery which is usually thrown away after this period. This battery will give 261 mWh. This means the daily need for energy for the biosensor module is (261/4=) 65,25 mWh per day. Using a safety factor of x2 the total energy demand would become 130,5 mWh per day which the generator should be able to provide.

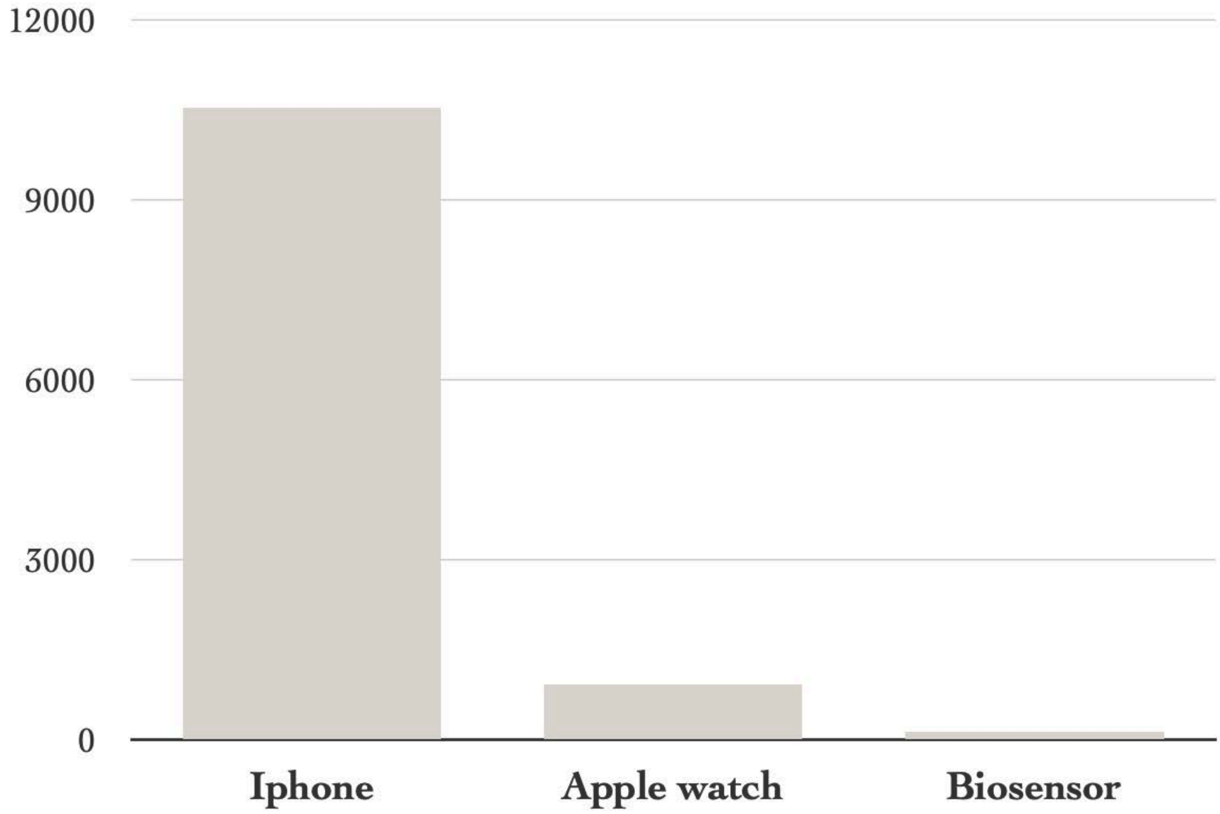


Figure 3: In the diagram the energy demand (in mWh) has been shown for the biosensor and 2 other consumer products. Showing these other two consumer product's energy demand serves as a reference point and indicated how energy demanding this biosensor is.

CONCLUSION:

The energy harvesting modules that are to be used should be able to generate at least 130 mWh per day.

2.3 PRODUCT AND INTERACTION

As the target group for this project is defined as the elderly, the interaction of this target group with the product should also be considered. As the user with the biosensor will go through their day the interaction with the energy harvesting system must not stand in the way of their daily routines and new criteria would come up. In the scenario, in figure 4 some key activities of an elderly person are illustrated after an observation of the target group in a day.

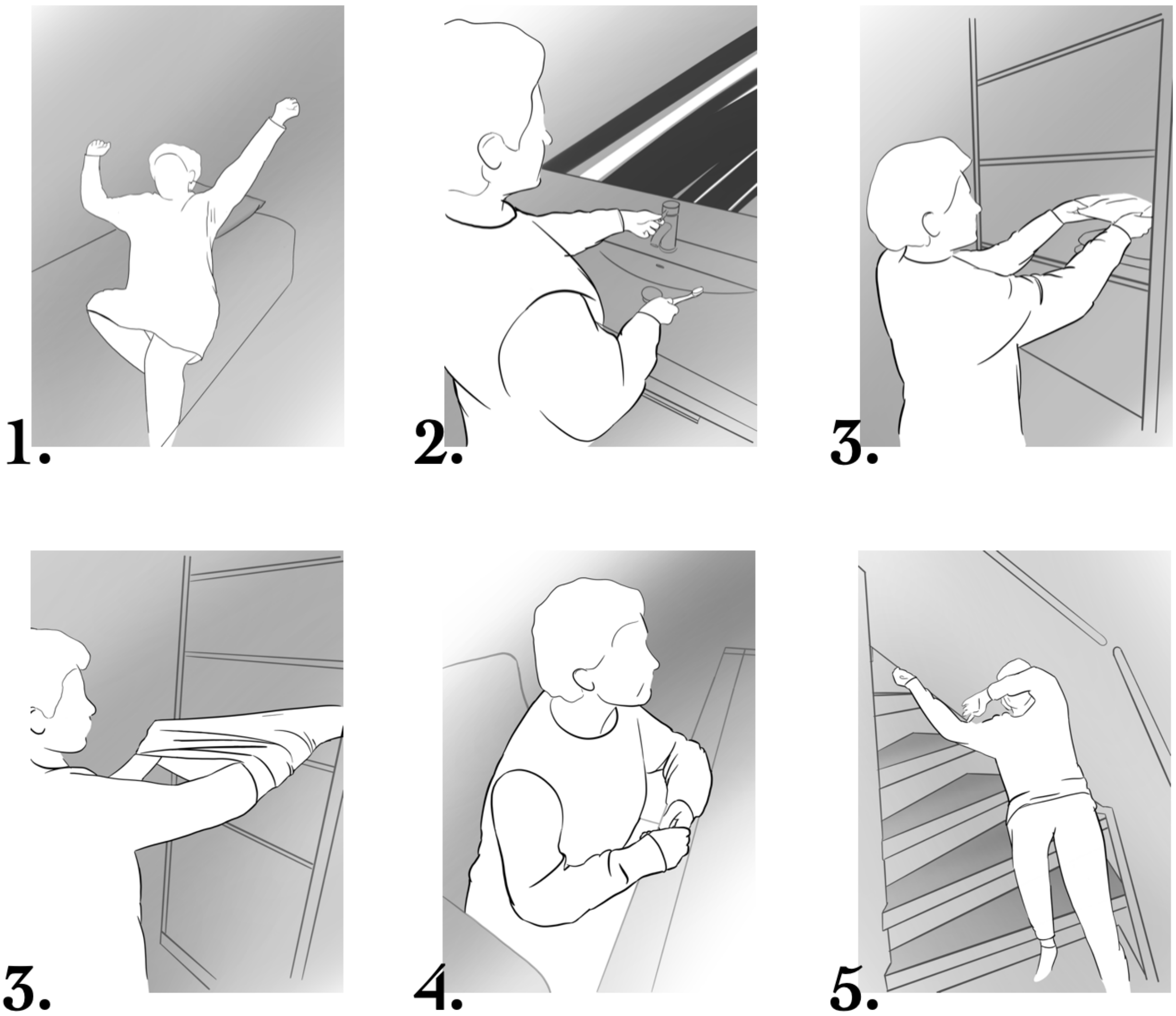


Figure 4: Illustrated scenario after target group observation

The morning starts around 8 o'clock after which the person goes to the bathroom. She brushes her teeth and takes a shower.

After this part of the morning routine, she heads back to her room and opens her closet in which all of the clothes are neatly folded. For the implementation of the energy harvesting elements folding clothes should be considered as well and these elements should be able to withstand these types of bending.

When changing into the clothes that are picked out it should be noticed that the items are stretched. For this matter, the embedding of the energy harvesting modules should also still work and in the same location after putting on the piece of clothing. The same goes for taking it off.

After changing into the right clothes for that day, the person will have breakfast and will sit in a chair. Sitting is an interesting position in which the back, arms, bottom-, and upper legs will rest on the seat. This pressure should not be a problem for the embedded energy harvesting modules. When having breakfast it is possible to spill some water with the result that it comes on their clothing. For this reason, it is important that the system should not shock the user when water damage occurs.

In the last figure, the person is illustrated after she has fallen. The biosensors that are discussed are able to identify if the person has fallen, the energy harvesting generator should therefore also be able to withstand the impact of a person falling.

CONCLUSIE:

The energy harvesting system should be able to withstand folding the clothes in which it is embedded.

The energy harvesting elements should be kept in place after stretching the piece of clothing when putting the piece of clothing on.

The energy harvesting system should be able to work after stretching the piece of clothing when putting the piece of clothing on.

The energy harvesting module should function normally after a sitting position.

The energy harvesting system should not be dangerous for the user after water damage occurs.

The energy harvesting system should also be able to withstand the impact when the user has fallen.

ENERGY EQUILIBRIUM

No energy is free. When generating energy the energy should come from a certain source therefore energy is still limited. Over history, scientists have been trying to make perpetual systems work.

Famous examples of these systems would be the different variations of Bhāskara's wheel.

A modern-day example of a perpetual system would be a setup with a lightbulb and a solar panel. In this system, the solar panel would generate energy from the lamp for the lamp and thus theoretically would work forever. However, these systems all contradict one or more of the basic thermodynamic laws. Two of the laws are especially applicable for considering the options of this thesis.

The first law stated that energy can be converted from one form to another but can not be created or destroyed in any form. This statement directly states the limited possibilities of this project. Implementing energy harvesting elements does not mean that the energy can be created from nothing. The energy should be converted from another form to the form that is needed.

The second law states that the state of entropy always increases over time. This means energy always tends to spread out through processes like friction. If the energy is to be generated from human movement, the system could also add friction to the movement the user is to make. If, for example, this system is dependent on the movement of the arm, the energy to move the arm would not be the exact same as the energy that is converted through the energy harvesting element.

This means that the energy harvesting elements could also make it harder for the user of the piece of garment to move as friction occurs. When integrating these elements it is important to not be noticeable in terms of comfort. The piece of garment in which the elements are embedded should therefore not restrict the user in a noticeable way.

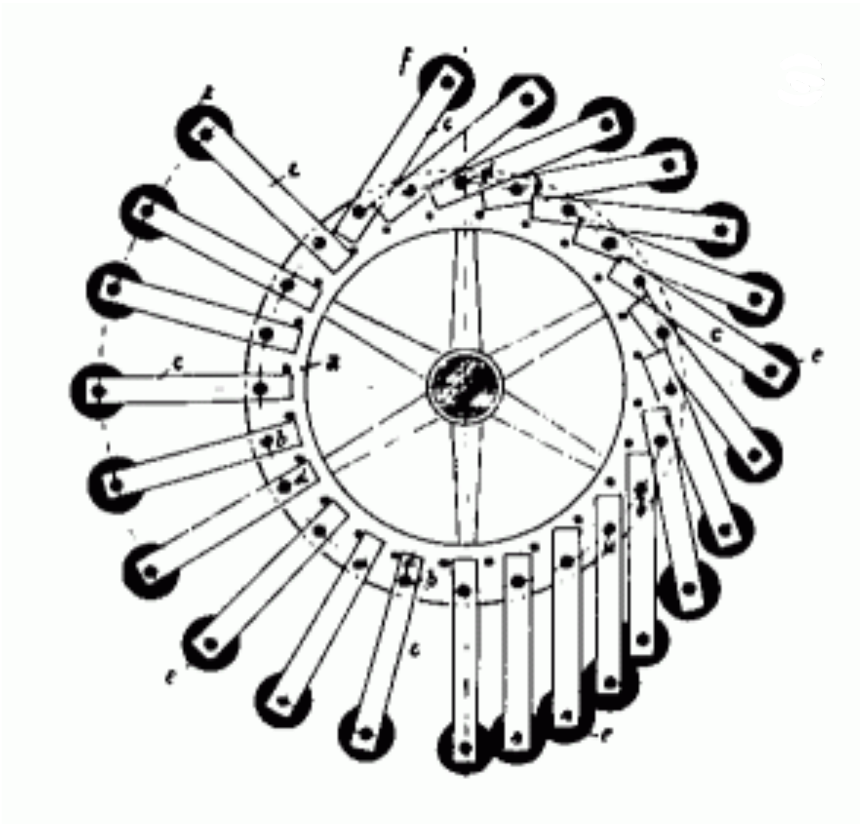


Figure 5: Bhāskara's wheel as a perpetual system

CONCLUSIE:

The energy harvesting element should not restrict the user with friction in a noticeable way so comfortability is not influenced.

LOCATION OF ENERGY HARVESTING ELEMENTS

Research conducted by Von Büren, Mitcheson, Green, Yeatman, Holme & Tröster (2006) has been done in order to optimize inertial micropower generators. In order to determine the most efficient location the test was done during a walking motion. In this study different locations on the human body are tested and evaluated. In figure 6 the measurement points are illustrated.

As these locations have been measured a division could be made of the head, the upper body and the lower body. The lower body has shown to be significantly better than the other measurement points. The lower body shows an average of 600% the output of that of the upper body and 1200% that of the head.
The study has shown that the largest absolute performance from human powered motion is that from the location of the knees and the ankles. Thus for the comparison, the location of the inertial micro-power generators is going to be on the lower body of which preferably the knees or ankles to maximize the power output.

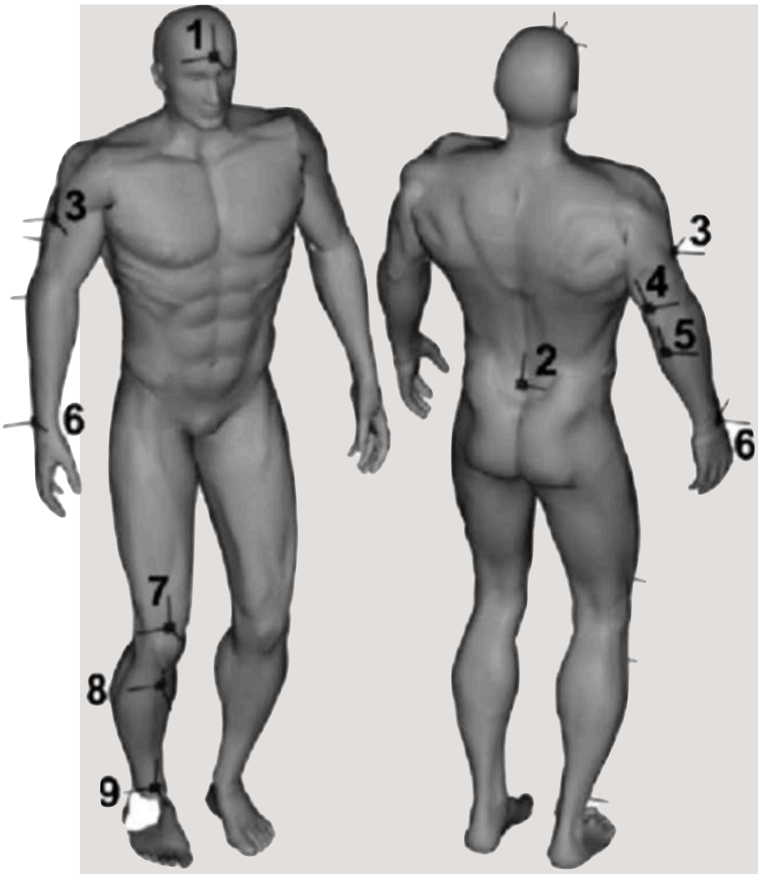


Figure 6: location of measurement points on test subject (von Buren et al., 2006)

PRODUCT CRITERIA

For further criteria the list Pugh's list for general product criteria has been used (Roozenburg and Eekels, 2013).

SURROUNDINGS

In order to make the energy harvesting system work effectively, the surroundings should also be taken into account. As for the method that will be chosen for the final product it is important that these can withstand the conditions in which they are going to be used.
First off the environmental influences of temperature should work for the energy harvesting method. As the energy harvesting system is to be implemented into clothing it should withstand room temperatures but also temperatures from outdoors. Considering that the temperature differs from place to place the highest and the lowest temperatures of Europe are taken. The final product should be able to work under those temperatures. Research shows that the most extremes were measured to be -55 °C and 48 °C ("Record-Setting Weather in Europe," n.d.). Although this minimum temperature is not one in which the target group spends most of their time, the minimum temperature is set up to a more realistic -15°C. This statement can be translated into a criterium which states that the energy harvesting system should be able to withstand temperatures between these two extremes

The second is the ability to work in humid conditions. As electronics are involved the combination with water is often a problem. The energy harvesting system is attached to clothing and should possibly also be resistant to rainfall or other moisture from sweat or mist.

CONCLUSION:

The product must withstand temperatures between -20 and 48 degrees Celsius.

The product must withstand light rainfall, sweat and humidity.

MAINTENANCE AND LIFESPAN

As the target group is the elderly the maintenance should be as low or easy as possible. This can be achieved by having no loose elements in the energy harvesting modules which can be broken. And eliminating the need for maintenance by the user him-/ herself. The final product, therefore, needs a design that does not give the user the availability to try and fix things when needed. This should be done for them by a specialist.

For the product's life span it is important to take into account the way of using the product. Considering the electronics being integrated with clothing it is expected that these clothes will also have to go into the washing machine after a certain time depending on what type of clothing it is. According to Kaspar Jansen most of the electronics that are embedded into fabrics break after a few washing cycles due to the friction in the washing machine. One of the more fragile elements are the conductive wires which act as the veins for smart clothing. Ideally, these wires should be attachable and detachable to the piece of clothing so that these can simply be taken off before washing and thus extending the lifespan of smart clothing. This thesis however will focus more on the energy harvesting elements as there is limited time. For these elements too, it is important to be protected for cleaning. In order to do so, the energy harvesting components should be able to be cleaned without the system failing afterward.

CONCLUSION:

The energy harvesting module needs to be able to be cleaned.

SAFETY

Safety is one of the most important aspects of criteria for products. As the product is to be used by the elderly no dangerous scenarios should be the cause of the system that is to be designed. Sharp or hard edges in the design should be avoided such that these do not form a possible threat to the user's safety.
Since electronics and textiles are going to be combined the electrical currents should also be secured such that the skin does not come in contact with the wires or other components that might carry an electric charge.

> **CONCLUSION:**
>
> The components of the energy harvesting system that have an electrical charge must not come in direct contact with the skin of the user.

3. ENERGY HARVESTING SYSTEMS

In order to create an energy harvesting system into clothing, diverse energy harvesting methods should be analyzed. This chapter will evaluate each method with the potential to be integrated. This is done by calculating the amount of energy that can be generated and the possibility to implement these elements into clothing.

3.1 ELECTROMAGNETIC CONVERSION

According to a study by Khaligh, Zeng & Zengh (2010), there are 3 main categories of electromagnetic generators. Respectively resonant-, rotational- and hybrid generators.
Resonant generators are generally known for the spring mechanism. This mechanism depends on an external force that resonates the spring which is mounted to a mass. This force creates a resonation in between magnets which is then converted to electric power.

“The rule of thumb states that the smaller the size of the object, the higher its resonant frequency will be. Therefore, it is difficult to design a miniature resonant energy scavenger to work on humans. As a result, for most piezoelectric generators in human applications, the piezoelectric patch is coupled either through direct straining or by impacting the kinetic driving source.” (Khaligh, Zeng & Zengh, 2010). These types of generators are also generally used for lower energy demanding systems. The capacity to generate energy for these types of generators is mentioned to be 1μW for a frequency of 70 Hz. Important for the implementation into clothing is the volume of this mechanism. The rather bulky mechanism shows poor suitability for the integration with clothing.
This statement further shows the poor suitability for this generator to be implemented in this project.

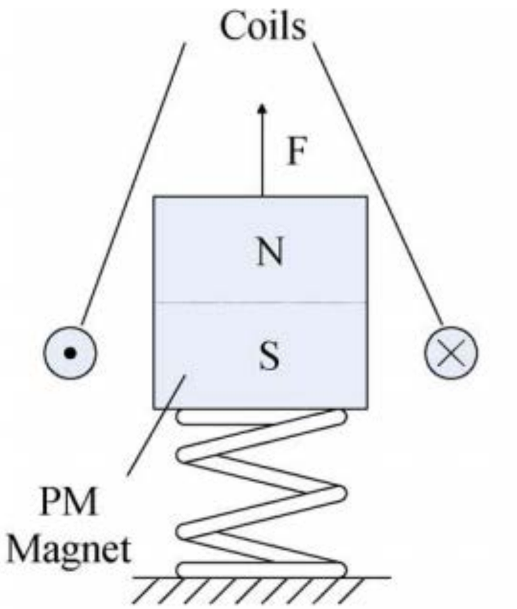


Figure 7: schematic illustration of resonant generators

Rotational generators are a category that might be most known to people as they are the most commonly used ones. These mechanisms work with dynamo's and rely on an external force that drives spools and magnets in a circular motion which then converts the mechanical power into electrical power. Initially, dynamo's are used with the external force being steam. The use of dynamos can be seen in many applications. These can be in products like the dynamo for the lamp on your bike, the “dyno torch” and even in modern gym equipment that generates the ended energy from the person exercising on it. The volume for these mechanisms could be relatively big due to the levers that are used for the transmission of the forces to the gears. This makes rotational generators a rather poor method to be integrated with clothing.

To further evaluate the possibility for a dynamo as a suited energy generator a calculation is made. For convenience, an example is taken in which the power in one hand is measured. With a newton meter, the force is measured which can be used to quantify the force which can be exerted with one grip. For this test, the measurement gave a measurement of around 100-200 N. Although the maximum grip force for both men and women are significantly higher (Nilsen, Hermann, Eriksen, Dagfinrud, Mowinckel & Kjeken, 2011) this gripping force was chosen as this one could comfortably be repeated every second. If this gripping motion of the hand were to move a product like a dyno torch and the displacement would be around 4 cm the power would be equivalent to a minimum of (0,04*100=) 4 Watt and a maximum of 8 Watt. The time in which this movement can be repeated without it being an annoyance will be no longer than one minute. In total, the amount of generated energy would be a minimum of 0,066 Wh or 0,132 Wh. If either the range of motion or the power was increased the power generation would do too. However, the current calculation has been done for the working ways of a dyno torch which is a voluminous and inefficient rigid product to be implemented into clothing.

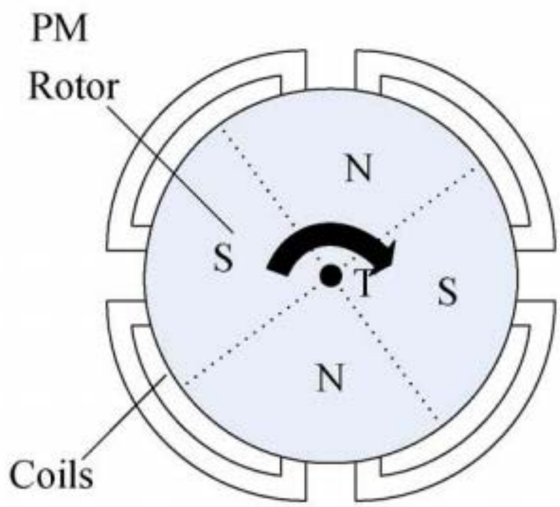


Figure 8: schematic illustration of rotational generators

The hybrid generators are different from the previous two categories. These types of generators are typically known for converting linear motions into rotational movements. The difference from the rotational generators is that these generators depend on resonant motions. An example of a watch generating its own energy with the use of this generator may be more familiar. Automatic watches generate energy by the motion of the arm and hands. Whenever the wearer is swinging with their arm while walking or making curtains movements these hybrid generators are capable of converting these movements into rotational movements of the loose PM rotor. Apart from the arm, these elements could also be placed at the ankles. In the example of this automatic watch, this generator creates enough energy to keep the arrows running for a week.

A watch specialist at the Bijenkorf Rotterdam stated that most watch modules require 1,5 V and 50 mAh. One battery provides a watch a battery life of 2 years (creativewatch, 2018) thus the watch needs (50*10^-3 /17520=) 2,85 µA per day. The energy a watch uses per day is (1,5*2,85*10^-6*24=) 0,1mWh. After wearing a watch with a hybrid generator for one day the watch stays running for about a week if the wearer is less active on one day we assume the watch only lasts 4 days. The energy that can be generated in one day of wearing the automatic watch, therefore, is (0,1*4) 0,4 mWh or 0,7 mWh.

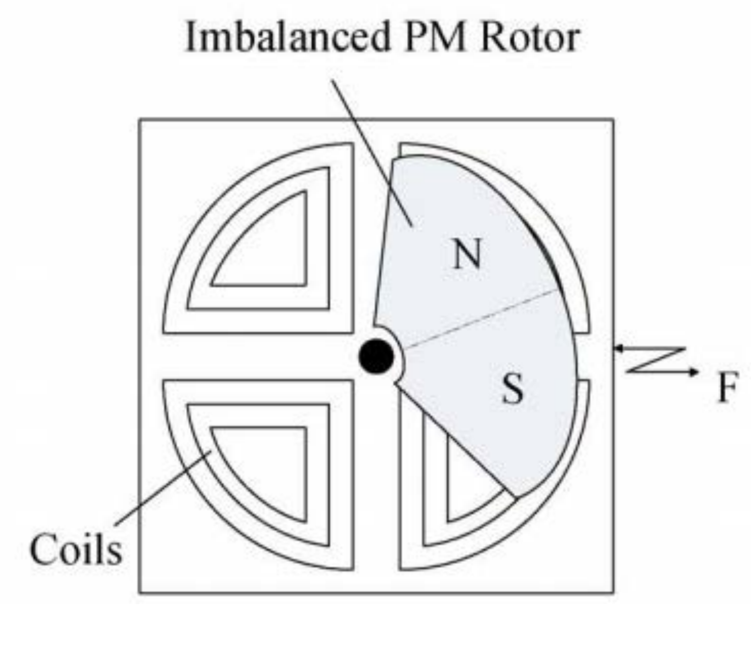


Figure 9: schematic illustration of hybrid generators

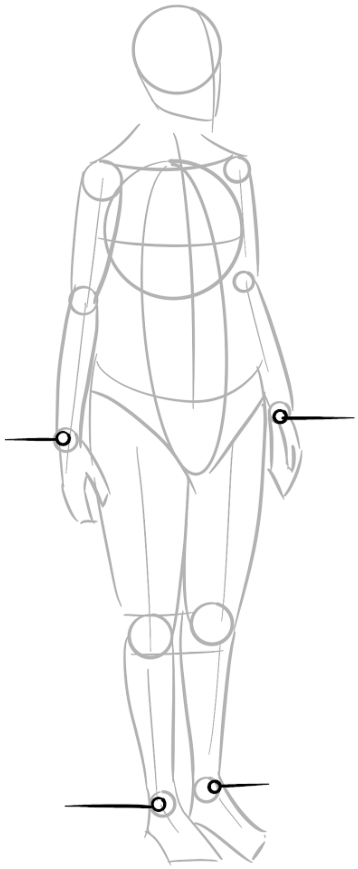


Figure 10: possible locations for the electro magnetic generators on the target group

The three electromagnetic methods all have advantages and disadvantages. However, the possibility to integrate these elements with smart clothing is crucial. When evaluating these methods it becomes immediately clear that the rotational generators will have a poor possibility to be implemented into clothing. The form of the rotational generator limits the seamless integration in clothing thus being less suitable.

Resonant generators too will have poor suitability for the implementation with smart clothing. As mentioned by Khaligh, Zeng, and Zengh (2010) it is difficult to design a miniature resonant energy scavenger to work on humans. Part of this is due to the rigid modules that need to be integrated with a flexible module.

Lastly the hybrid generator. This generator is relatively small as it can be integrated into a wristwatch but does generate little energy per generator. The possible location for this method however is mostly restricted to the wrist and the ankles.

3.2 PIEZOELECTRIC GENERATORS

As the name suggests piezoelectric generators are based on the piezoelectric effect. Stress in the form of both compression as tension would mean that this mechanical energy can be converted to electrical energy. The piezoelectric device consists of 2 metal plates and a piezoelectric material in between them. Compressing this element changes the polarisation of this material and creates an electrical field. The metal plates on each side collect these charges and thus convert these movements to electrical energy. This can be seen in figure 11.

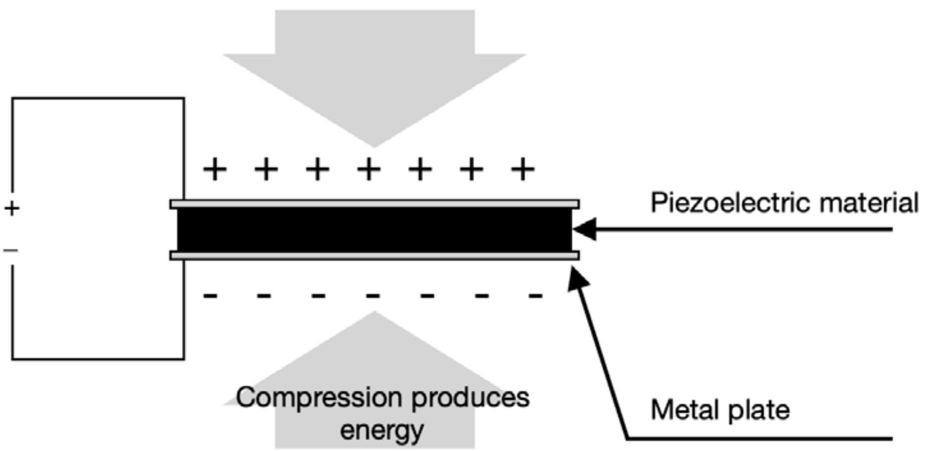


Figure 11: Schematic illustration of piezo electric generators

The amount of energy that can be won from a mechanism like this depends on several factors like the type of piezoelectric material, the design of this device, the frequency of compression, and the applied force. The available power that can (in theory) be generated from a surface which is around 15 by 15 cm is mentioned to be 67 W for a person who weighs 68 Kg (Starner, 1996). This calculation has been done for a situation in which a person is walking normally and the piezoelectric area has been placed in the shoe. This place has been chosen as this is one of the most efficient places for a piezoelectric generator to be placed at utilizing all of the weight of a human being. In this situation, an average of 2 steps per second has been taken and a fall of the heel of 5 cm. However, taking into account the efficiency of the conversion of mechanical to electrical energy reduces the potential power of 67 W significantly. "With a mechanical power loss of 75%, electromechanical efficiency of 50%, electrical power loss of 10%, and daily rate of 16.6%, the theoretical limit of piezoelectric energy harvesting is approximated to be 1,265 W" (Khaligh, Zeng, & Zheng, 2010).

Getting to 8000 steps per day is more attainable than the 10000 steps which is often strived for (De Nederlandse Hartstichting, n.d.). As mentioned earlier taking 2 steps per second will leave us walking for 4000 seconds a day. According to Khaligh, Zeng, & Zheng (2010), the energy that can be generated in one day is 1,4 Wh. Taken into account that an elderly person walks around 17%-66% less than average, the time spent walking on one day is (1,1*0,33) 0,36 hours minimum and 0,91 hours maximum. This means (1,265*0,36) 0,46 Wh minimum and 1,1 Wh maximum can be generated in one day.

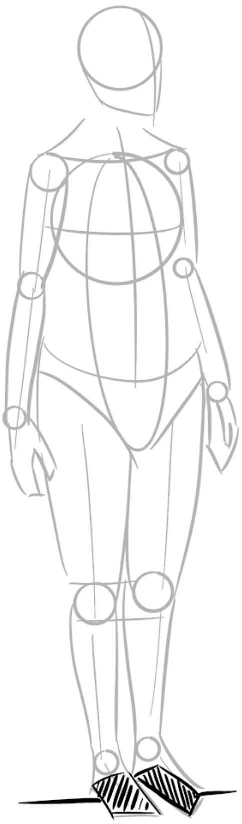


Figure 12: possible locations for the Piezoelectric generators on the target group

POLYVINYLIDENE FLUORIDE OR POLYVINYLIDENE DIFLUORIDE (PVDF)

Another type of piezoelectric generator would be Polyvinylidene fluoride or polyvinylidene difluoride (PVDF). This application of piezoelectric generators is flexible which allows them to generate energy through bending. Using these characteristics allows us to implement these elements into the upper body. The benefit of the implementation in another location than the shoes is that the potential to be part of an integrated system is greater. Possible locations for these types of generators are mentioned earlier like the elbows, knees, and ankles.
In a study conducted by Proto, Vlach, Conforto, Kasik, Bibbo, Vala & Schmid (2017) the location for the PVDF films has been placed at various places of which the knees show the best suitability due to its higher power output. The knees show a power output of 0,002 mW for walking with the use of a film with the following dimensions: 15,6 cm x 1,9 cm. If the area is increased with factor 7,9 (15x15 / 15,6x1,9) the energy output can be compared with the ones of other energy harvesting methods as this resembles the 15 x 15 cm size. Using this calculation in a calculator would mean that the energy generated in one day would be 5,7 mWh minimum and 14,4 mWh maximum per day. However, even after increasing the generator's area, the energy output is relatively low.

The freedom which the PVDF provides compared to the piezoelectric generator shows comes with a cost. The PVDF can generate significantly less energy than the piezoelectric generators and therefore makes the latter still the better option to power the biosensor that is discussed in chapter 2

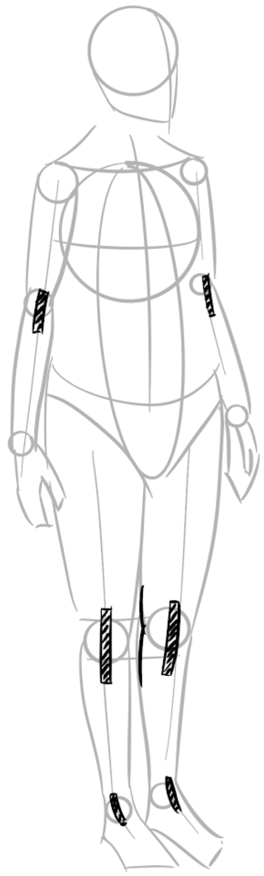


Figure 13: possible locations for the PVDF generators on the target group

3.3 TRIBOELECTRIC NANOGENERATORS

Triboelectric nanogenerators or TENG's are another type of generator that converts kinetic energy to electrical energy. TENG's harvest energy by harnessing the phenomenon of static energy. When two different materials come in frictional contact with each other they exchange electrons. This uneven distribution of charge can be connected to a circuit and thus benefit from the energy that it generates. The larger the difference in electron affinity of the materials that are used. The greater the potential charge. TENG's can cooperate in different ways which all have different advantages and disadvantages. One of the most common ways of using TENG's is the vertical contact mode. This complements best the ways of human motion and therefore is also well suited for smart clothing implementation. A new possibility to embed these elements into clothing has been researched by Zhou, Zhang, Han, Fan, Tang & Wang (2014). The model of these generators has been redesigned into a piece of fabric and is called woven structured TENG (W-TENG). The redesign would allow for these generators to be more flexible and unnoticeable by the user; perfect for the application in textiles and clothing.

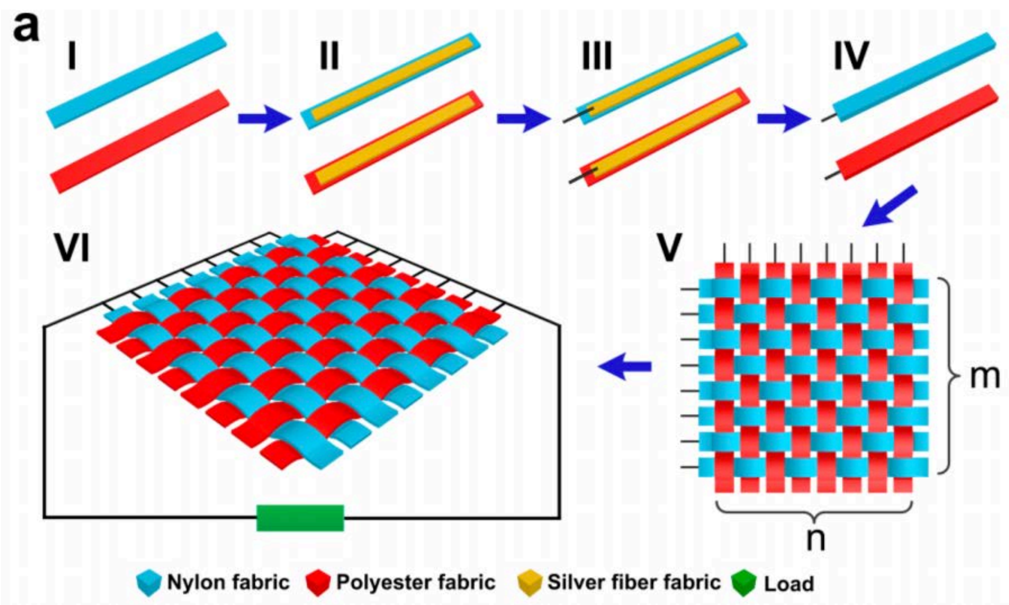


Figure 14: Schematic illustration of the W-TENG composition of plastics and metals

Due to the innovative architecture of the W-TENG modules, there is a preference for this type of generator rather than the traditional one. The flexible characteristics fit the direction in which technology and the clothing industry are heading which makes it interesting to use for this project too. The locations for this type of energy harvesting elements could be on multiple locations as these allow for easy integration. In figure 15 the locations of the elbows and knees are shown as possible locations in which these elements could be embedded.

The use of W-TENG is shown to provide 0,5 - 0,8 μA as a short-circuit current and an average of 20 V as an open-circuit current. This is done for the location of the knees when the person is walking. Together this would mean that this way of energy harvesting would be good for 10 - 16 μW with the used size of the W-TENG which is 15 by 15 cm. On average an elderly person takes around 6000-8500 steps a day according to (Tudor-Locke et al., 2011). When assuming the frequency of the elderly's walking speed is 1 step per second the deduction can be made that a maximum of 2,4 hours is spent walking a day. If this piece of clothing would be worn during one day the user would wear the piece of clothing for around 2 hours which lead to (2*10*10^-6=) 0,02 mWh.

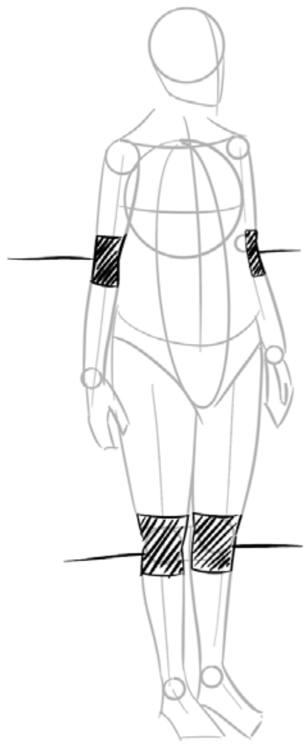


Figure 15: possible locations for the turboelectric nanogenerators on the target group

The energy this generator is able to provide does not support criteria of generating at least 130 mWh. However the use of W-TENG could be used for a much bigger area as the material is similar to the traditional synthetic clothing textiles. On average the size of fabric needed for a medium size T-shirt is 150 cm x 100 cm. If an entire T-shirt is made from W-TENG and we assume the entire body is going to generate as much energy as that can be won from the placement around the knees we should multiply the energy output with ((150*100)/(15*15))= 66,67. Even in this scenario the maximum amount of energy that can be harvested would be 1,3 mWh. This would still be insufficient for the use of the biosensor.

3.4 SOLAR ENERGY

Solar energy is another way of converting the sun's rays into electrical energy. Solar panels consist of silicon and cristal being sandwiched between two conductive layers like metals. The middle layer consists of two types of silicon. One with more electrons and one with less. The layer with fewer electrons thus has a positive charge while the other layer has a negative charge. The electrons of the negatively charged layer can be moved when struck by a photon that comes from the sun through sunlight. When this is done the electrons move from the conductive layer through a circuit and go back to the positively charged layer of the solar cell.

The application of solar panels can often be observed on buildings and other rigid objects. Flexibility has been one of the issues for solar panels but relatively new technologies made it possible to produce these types of solar panels commercially. Pauline van Dongen and Maaike Gottschal have been working on a new shirt in which the solar cells are completely embedded in the textile of the garment (oneworld.nl, 2020). This project is an iteration of an earlier project van Dongen did in which small solar cells were attached to clothing like jackets, backpacks, a dress, and shirts. This project also suggests the possibilities for the location of these solar cells to be almost anywhere on these shirts, dresses, and jackets.

Van Dongen stated for this earlier project that wearing the pieces of clothing for two hours in the sun the user is capable of using that energy to fully charge your phone from 0 to a hundred percent. If the area covered with solar cells is greater the amount of energy will be too. This can be accomplished by integrating more flexible solar cells.

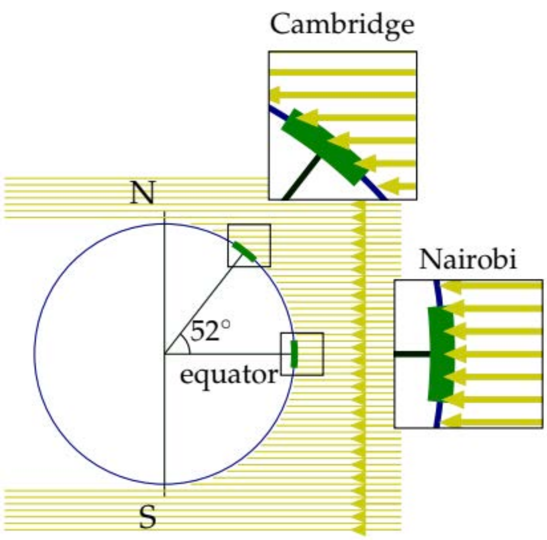


Figure 16: Sunlight angle calculation for the Netherlands

The dependency on the sun is an important factor when considering this method for energy harvesting. Whereas the power potential of the sun is mentioned to be 1000W per square meter on a cloudless midday (MacKay, 2009). However, this is the optimum scenario. It's not midday all the time nor is the sky cloud-free all year. The intensity of the sunlight is also dependent on where the solar cells need to be working. For instance, in the middle-west of Europe, we also need to consider the angle of sunlight as this lowers the intensity of the sun's power. For The Netherlands, this intensity is around 60 percent of what it would be at the equator. However, the intensity for a cloud-free day in March or September is approximately 30 percent which may decrease if coverage from clouds occurs. The amount of sun during the day should also be considered. In The Netherlands, the maximum percentage of sun hours is 39%.

Combining these three factors results into a yearly average sun power would be equal to around 100 W/m^2 (MacKay, 2009) which takes into account the fluctuation of the seasons and their weather. This given value can be translated to a potential power generation of 1,75 - 2,25 Watt on a surface of 15 by 15 cm. While this amount of power can be generated when going outside with the solar panel, not everyone goes outside all day. Solar panels do work indoors but the light intensity can be lowered by a factor of 1000 thus decreasing the potential power to 1,75 - 2,25 mW (Jones, 2018). A study has shown that people spend 13 percent per day outside buildings, which is around 3 hours (Diffey, 2011). Assuming a person would wear their outfit for 12 hours a day the remaining 9 hours are spent inside. In total the energy that can be generated is ((2,25*3)+(0,00225*9)) 6,78 Wh maximum and 5,3 Wh minimum.

FLEXIBLE SOLAR CELLS

The implementation into clothing flexibility broadens the possibilities for integration. Flexible solar cells seem like the right solution to the restrictions that rigid solar cells seem to bring with them. However, flexible solar cells have a downside compared to rigid collar cells. The flexible cells are mentioned to be less durable and have a lower efficiency. Also, the durability of the flexible solar panels is lower because of microcracks that may occur when bending the material. Over time these affect the cells to work properly. The efficiency may be reduced over time or the cells completely stop working.

The efficiency of flexible solar cells is lower than that of the traditional rigid ones. Whereas the rigid solar cells usually have an efficiency of 16-22% the flexible have a significantly lower efficiency of 13-17% (Solar Solution Solar Solution, 2020) (Matich, 2020)

Within the market of solar panels, the prices can range from cheaper to more expensive panels. costly ones are often encapsulated with glass whereas the more low-cost ones have a polymeric encapsulation. One of the most used polymers used for solar cells is polycarbonate (PC). While the refractive indexes for glass and PC are the same (CES Edupack) the solar panels can show a difference in their efficiency. Michel Oosterkamp, an advisor at Energiewonen, stated that the downside with plastic solar panels is that scratches form easily. These scratches will influence the ability to absorb the number of photons that strike the panel. The cheaper panels with polyester also often have the problem of water vapor that comes in between the layers. Lastly, the thermal conductivity of glass is higher than that of polyester which allows for better temperature regulation of the solar panel.

Flexible solar panels show a better implementation ability with clothing. The downsides are the lower durability due to the microcracks which affect the efficiency compared to the traditional rigid ones. Using the flexible panels would mean that the minimal potential power output of the panel of size 15 by 15 cm would be ((2,25/22)*13=) 1,3 W. The maximum would be ((2,25/22)*17=) 1,7 W. When using these indoors the maximum potential power would be respectively 1,3 mW and 1,7 mW. For the flexible solar panels the total amount of energy that can be generated in one day is a minimum of ((1,3*3)+(0,0013*9)=) 3,9 Wh and a maximum of ((1,7*3)+(0,0017*9)=) 5,1 Wh.

Using solar cells as the method to generate energy seems like a suitable method as the required amount of energy can be easily achieved even if the majority of daytime is spent indoors. When integrating flexible solar panels we are not dependent on the amount of movement of the user. This allows for a greater surface that can be covered with solar cells. Possible locations can be seen in figure 17.

The negative aspect of the application of solar cells is the need for them to be on the top layer of clothing. If the solar cells are covered by a jacket, vest, or other pieces of clothing the generator's functionality is lost and no energy can be won. In this sense, the limitation for these energy harvesters is the need that they should be placed on a top layer.

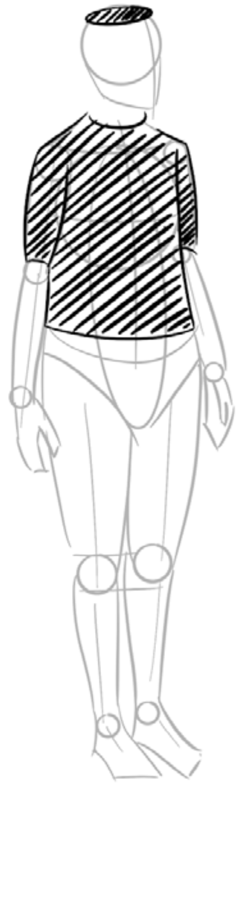


Figure 17: possible locations for solar cells on the target group

3.5 THERMO ELECTRIC GENERATORS

Thermoelectric generators or otherwise known as TEG’s are capable of converting a temperature difference into electrical energy. When heating one end of metal while simultaneously cooling the other end, the electrons on the hot end move faster than the ones on the cold end. The electrons of the hot end will move faster to the cold end than the electrons moving from the cold end to the hot end. This causes the cold end to be more negatively charged while the hot end gets more positively charged.
The advantages of this type of generator are the reliability and the lack of moving parts. The use of thermoelectric elements has been studied to use in aerospace and in the automotive industry. Heat often is one of the byproducts of conversions of mechanical operations. One example is the generation of energy with the use of a conventional power station where 66,67 percent is lost in the form of heath.

The human body also generates heat to keep the right body temperature and gets warmer when any form of activity of the human body is initiated. Harvesting this energy by using the body- and outside temperatures could offer great potential. However, this method will not be applicable due to the high-temperature difference that is needed for TEG’s. TEG’s work best with a temperature difference of several hundred degrees which is not achieved by comparing a place on the human body with outside temperatures.

3.6 WIFI WAVES

New technology has enabled us to make use of certain radio frequencies that are transmitted through the air to make our devices work. Examples of these frequencies are the router providing a wifi signal, our devices transmitting Bluetooth, LTE from our carriers' masts, and more. The rectenna that was developed converts an AC (wifi signal) to DC (usable power). According to Xu Zang, postdoctoral, this development is suited for the future of wearables due to the flexible semiconductor that is used for the device. The researchers claim that the semiconductors can be made by using a roll to roll process such that larger areas can be covered like ceilings or walls (Bell, 2019).

Zhang et al. (2019) tested the rectenna and found the device to be able to generate a power of around 40 µW with the use of typical power levels of wifi signals. The area of the rectenna was 12,5 cm^2; if this would be a sheet of 15 by 15 cm the power would be 0,72 mW. Given that people spend around 9 hours inside buildings would come to a total of 6,48 mWh. Due to the

However, the intensity of the wifi signal can be lowered by walls and distance from the router. For this rectenna, a distance of 2 cm from the commercial wifi router was held. This distance can not be kept when integrating these devices into clothing thus marking this method for energy harvesting as a poor fit.

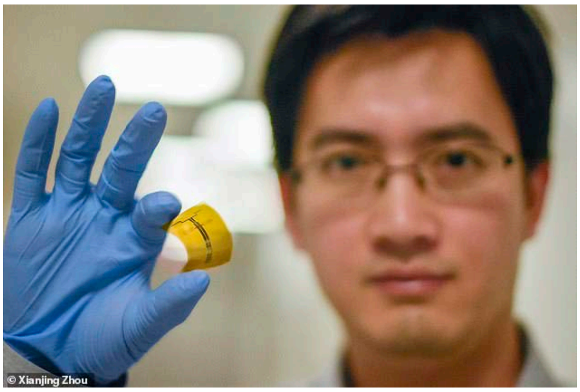


Figure 18: Rectenna used for conducting the research (Zhang et al., 2019)

3.5 THERMO ELECTRIC GENERATORS

The working principles for each of the energy harvesting methods have been highlighted after which the implementation possibility has been mentioned. To make a comparison of the methods the energy supply from each method has been calculated. This energy supply is calculated by taking into account the usage of the respective energy harvesting method for one day. This energy supply should be enough to support the earlier set criteria which states the minimum amount of energy that is needed to power the biosensor for one day. In figure 19 the energy harvesting methods are listed according to the amount of energy that they produce. The ones that generate a sufficient amount of energy for the biosensor will be marked green. After this further criteria will determine the further ranking.

For figure 19 the weighted criteria method was used that is mentioned by Roozenburg and Eekels (2013). The scores are given for 6 different criteria which are important for the execution of this project. For the first criteria, the energy supply is given a score to what extent this would suffice to provide the biosensor with the required energy. When the energy harvesting method is not capable of generating enough energy the score given to this method will be 0.

The location of the energy harvesting elements should be in the right place to create an efficient system. The aim of the system is to power the biosensor. This is meant to be put on the chest of the person. If the distance between the energy harvesting element and the biosensor is kept short, the infrastructure to direct the energy to the biosensor is also more efficient. Or this reason the location of the energy harvesting element should preferably be near the chest area. This criterion is mentioned as C2 in figure 19.

As clothing is also flexible and stretchable the energy harvesting element should be able to withstand these possible movements. By integrating an energy harvesting element that is also able to bend with the piece of clothing a more uniform feel can be given to the piece of clothing. This criterion is important for the ability to create a possibly more comfortable and more seamless integrated system. This criterion is mentioned as C3.

The size of the energy harvesting elements is also given a score. The bulkier the energy harvesting elements are the harder it would be to implement these seamlessly into fabric/ clothing. For this reason, volume is taken into the weighted criteria method as C4.

Availability will be mentioned as the criterion which will determine the feasibility of this system. As the possible energy harvesting elements could be on different levels of sophistication the extent to which these elements can be obtained also differs. Giving a score to this criterion will be done under C5.

Lastly, the price is taken into consideration. This criterion is important to not lose out of sight. As the price of the system can be kept low, the desirability and possibilities to implement these systems into clothing would go higher.

Energy harvesting Method	Energy supply (mWh per day)	C1 Energy supply score	C2 Practical location	C3 Flexible	C4 Volume	C5 Availability	C6 Cost price	Score
Weight factor		35	20	15	15	5	10	
Rigid solar cells	5300 - 6800	9	8	1	7	9	9	730
Flexible Solar cells	3900 - 5100	9	8	8	7	8	8	820
Piezoelectric generator	460 - 1100	8	4	1	9	9	9	645
Rotational electromagnetic converter	66 - 132	6	2	1	3	9	9	445
Pvdf	5,7 - 14,4	0	7	8	9	6	6	485
Triboelectric nanogenerator	0,12 - 0,2	0	7	9	7	4	1	410
WiFi waves	6 - 6,5	0	9	8	8	3	1	445
Hybrid electromagnetic converter	0,4 - 0,7	0	7	1	5	7	7	335
Resonant electromagnetic converter	-	0	-	1	5	6	7	-
Thermoelectric energy harvesting	-	0	-	1	7	8	9	-

Figure 19: Energy harvesting methods evaluation table

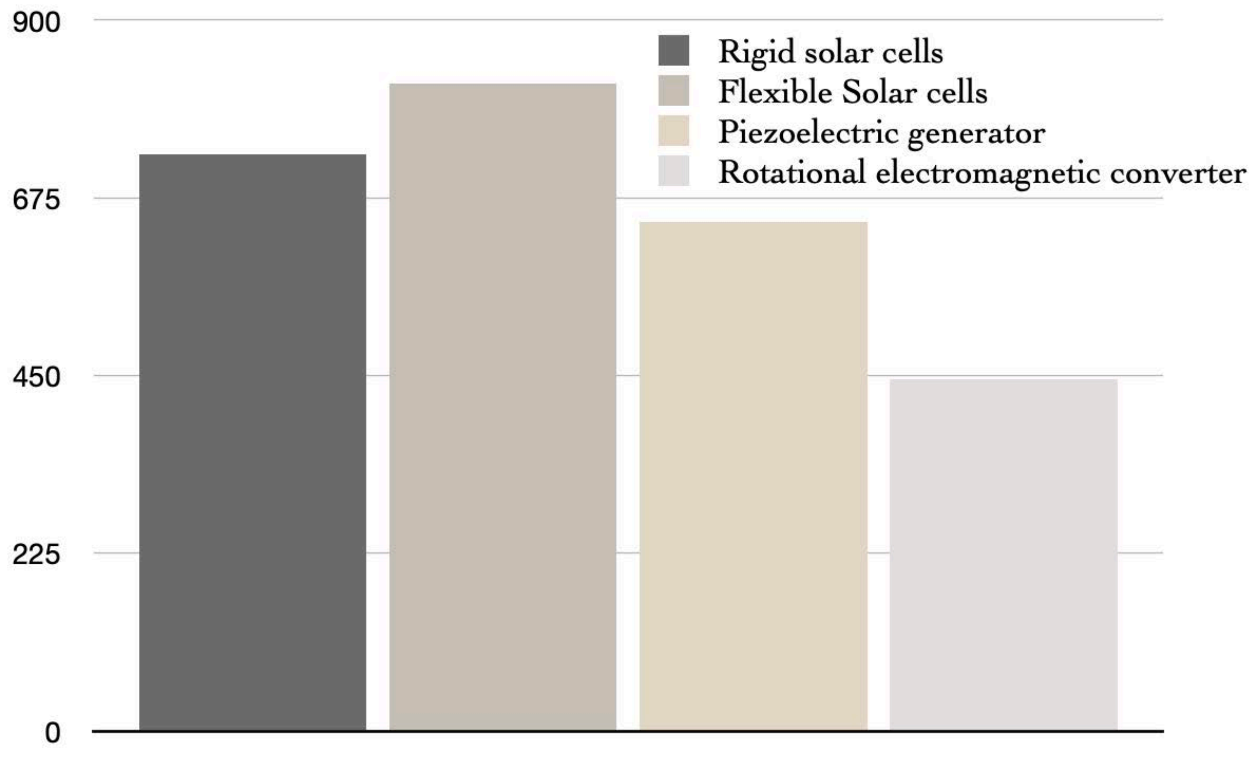


Figure 20: Energy harvesting methods evaluation bar chart

Figure 20 shows the methods and their compatibility with the set of criteria. Rigid solar cells, flexible solar cells, and piezoelectric generators seem like the best-suited options. These methods are able to generate enough energy for the biosensor for one day and have the highest score of the ones that can provide a minimum energy supply of 130 mWh.

The use of piezoelectric elements shows great potential as this method gathers energy from one of our most frequent movements: walking. Multiple studies have shown the benefits of walking for the elderly and are thus advised to do so every day if possible. Piezoelectric discs could be implemented in soles which can be used in every shoe and thus create an easy “stand-alone system” rather than and complete embedding in a piece of clothing or into one specific shoe. However, as the piezoelectric generators are placed on the bottom of the shoes the gathering of the energy is likely to also be done in the shoes. If the placement of the biosensor is likely to be on the person’s chest, the energy harvesting system is rather far from the place where the energy is needed.

The use of solar cells also shows great potential. These generators have been used before to power even more energy-demanding devices like smartphones and its concept of being able to combine with textile has been proven too. Using solar energy is a rather “older” method compared to some other methods that were initially taken into the analysis. As solar energy seems like a more mature method, the efficiency may also be much higher. Further innovation is also likely to happen in terms of efficiency. Due to the higher score and the bigger potential due to market demand the implementation of solar-powered generators may be the best suitable for this project.

CONCLUSION:

After evaluating multiple energy harvesting methods the use of solar panels seem like the better fit. This method is able to generate enough energy for the biosensor, and is shown to be working in earlier products and show potential for further development as this technology is more “mature” compared to the others in the analysis.

4. TECHNOLOGY INTEGRATION ANALYSIS

The integration of technology into wearable products needs to be done strategically. The combination can be a challenge as electrical elements are often more rigid. These elements need to be put into the right embodiment while still being completely functional, comfortable.

Figure 21: Solar shirt by Pauline van Dongen (Pauline van Dongen, 2020)

4.1 THE SYSTEM

“Design of an energy harvesting system for smart clothing”. A system consists of multiple elements which should be considered in order to deliver a final product for this thesis.

CAPACITOR

For the system that is to be developed the biosensor will be dependent on the energy that is to be generated by energy harvesting element(s). When a product is dependent on the energy harvesting module figure 22 describes the energy road.

If, for some reason, the energy harvesting elements are not able to generate enough energy the product that depends on its energy can not work properly. As an analogy, the idea of a bike and its lamp can be taken. If the person on the bike is to bike slower the intensity of the lamp would also be lower. This is due to the lower power that is being delivered to the lamp. In order to create a more secure system, the use of a capacitor can be used. This capacitor can store the energy that has been generated. If the energy harvesting element is not able to generate enough energy the capacitor would if “charged” properly, provide the energy for the biosensor.

For the biosensor, the voltage should be similar to that of the zinc-air battery that is currently. The voltage mentioned on this battery is 1,5V.

Figure 22: Energy road

Figure 23: Secured energy road

CONCLUSION:

For the system a capacitor, which is able to supply 1,5V, has to be integrated to momentarily store the energy generated by the harvesting element.

WIRING

Conductive yarn is specially made for compatibility with clothing. The conductive yard consists of thin conductive wires that are typically metal. Depending on the types of metal the specifications of the wire differ eg. the conductivity. By producing these extremely thin metals these can easily be integrated into clothing with the use of a needle.

Figure 24: Conductive yarn

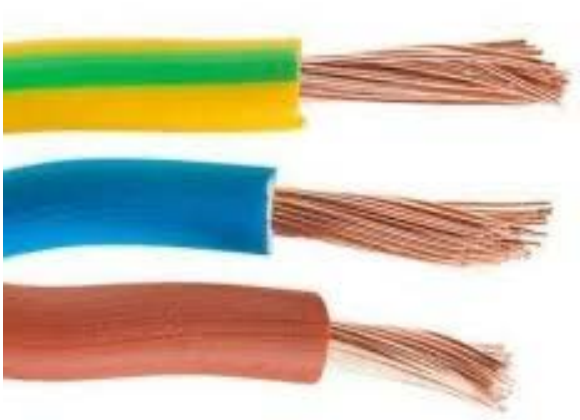


Figure 25: Common conductive wires

Standard cables are thicker and less “flexible” compared to conductive yarns. The thicker diameter of the conductive wires allows for lower resistance and can withstand a higher voltage. While these wires are thicker they do stand out more than the conductive yarns but these can also be integrated correctly. Examples are to integrate these in the seams of clothing or the inside of clothing. These wires are also isolated by a silicon rubber encapsulation.

Figure 26: Conductive cloth

Electrons could also be transported by creating a sheet of conductive wires. The forms of these sheets can be made such that they cover an entire area of the piece of clothing. Also, thinner strips could be made. This architecture of conductive wires allows for more freedom on the place of connection.

A combination of both textile and conductive wires could also be made. These form the textile ribbon cables. The benefit of these wires is that the conductive wires can be put into the textile strip. Putting these wires in a zigzag pattern allows for more flexibility which makes them able to cope with the stretchability of the textile.

Figure 27: textile ribbon cable with embedded conductive wired

According to research by (Cai, 2020), ribbon cables score significantly better on the reliability of the connection technique, simplicity of the connection technique and fits in the relatively lower price category. As these criteria benefit the limited timespan of this project the textile ribbon cables seem to be an acceptable fit for the earlier prototypes of this energy harvesting system.

4.2 AESTHETICS AND FUNCTIONALITY

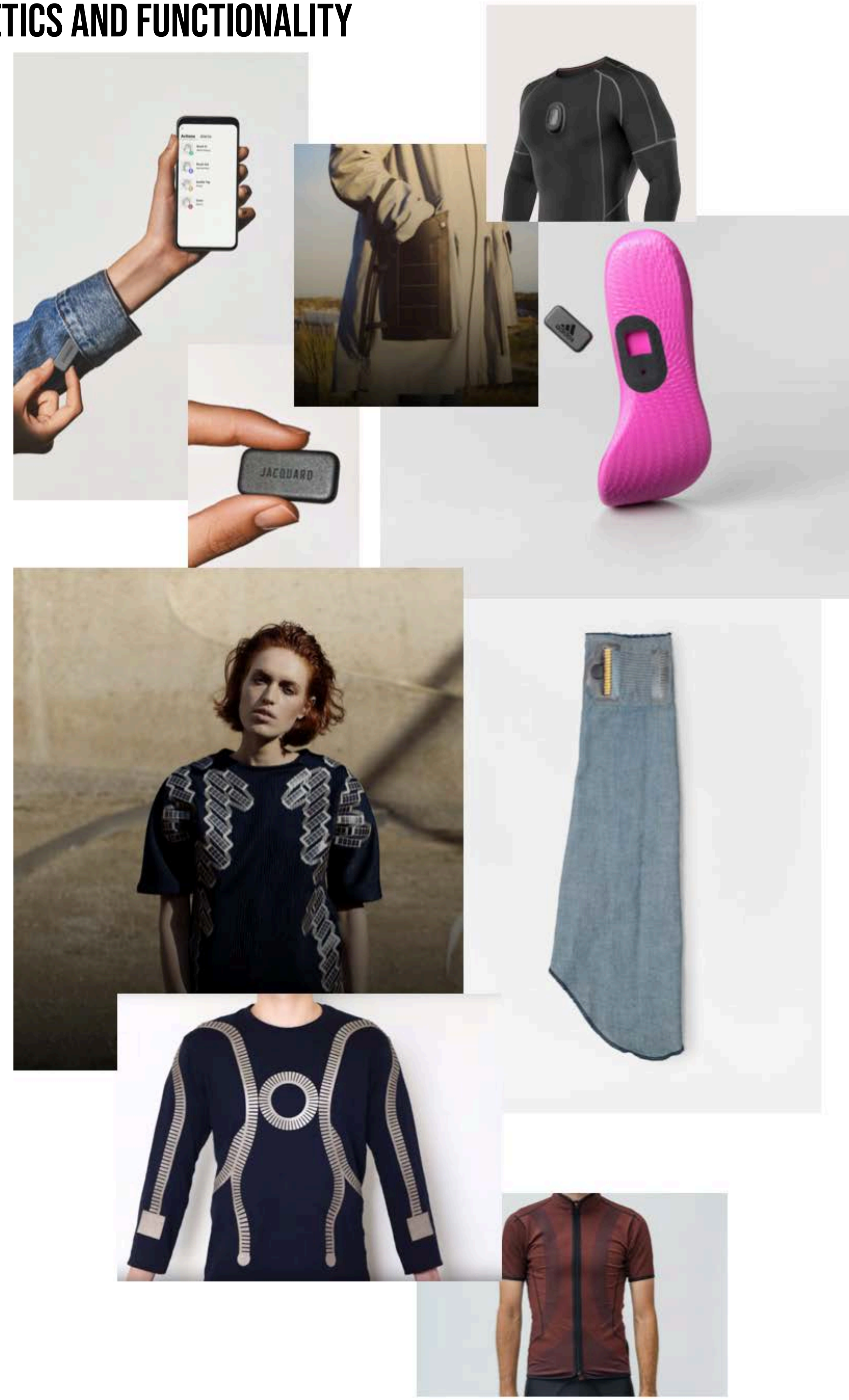


Figure 28: Electronics integration examples

Noticeable in figure 28 is that most of the integration is done in a non-obtrusive way. When implementing technology it is noticeable that most of these commercial items seem like traditional clothing.

The examples of the solar cells however are noticeable and are used in a way that these components are to enhance the aesthetic of the piece of garment like Pauline van Dongen did with her solar collection. The choice for making these solar panels more notable in her design is likely done because of the need for these cells to be exposed for them to be effective. In all other designs which she made the technological components were embedded more discreetly. The reason behind this may be an effect of s statement which was proven to be true in literature: “fashion’s primary consideration is a garment’s aesthetics and the message it communicates rather than its function, the 4.0 fashion garment is the least developed area in the fashion industry” (Seymour, 2011). For this reason, the embedded energy harvesting system should also be done in a non-obtrusive way. In order to maintain a certain level of desirability, a test for the prototype should be done with the target group to validate the desirability and improve for further iterations.

CONCLUSION:

As the main reason for people to buy clothing is still the aesthetic. In order to keep the desirability of the final product to be high the embedding should be done in a non-intrusive way. A test will be conducted with the target group in order to validate the prototype.

4.3 PLACEMENT AND COMFORT

In order to integrate the elements for the energy harvesting system comfortability and the way of attaching these elements should be considered. Analyzing the examples of other businesses should provide a basis of the possibilities that can be considered for the ideation phase.

The Jacquard module is one of these examples. While these modules are connected to the piece of clothing through Bluetooth, they are still to be put into a special place where the user will notice little to no discomfort. One such example figure 29 is the special sole. This sole is made specifically to make the jacquard module fit in without the user's comfort to degrade compared to an ordinary shoe sole. The other example can be seen in figure 30 and shows the jacquard module to be inserted into a special module to be inserted into a special pocket at the end of a denim jacket's sleeve which should.

Figure 29: Jaquard module in shoe sole

Figure 30: Jaquard module in denim jacket

Figure 31: Ambiotex shirt

Figure 32: Hexoskin shirt

As athletic wear is often known for the stretchability and it being comfortable these types of products can provide more insight into the possible locations and ways for comfortable integration of the energy harvesting system. These other examples can be seen in figures 31 and 32. These examples by Hexoskin and Ambiotex integrate rigid elements that are bulkier compared to the jacquard module. Also are these dependent on a wired system whereas the jacquard system relies on Bluetooth.

Hexoskin collects data from integrated sensors that are covered in the shirt by fabric and stores this information in a receiver which should be kept in a side pocket of the shirt. By covering these more rigid components with the flexible fabric the user will experience less discomfort and the sensors/receivers are kept in place. A certain pocket is made to keep the rigid hexoskin device in place. The location of the hexoskin device is placed at the sides of the user.

Noticeable is that Elitac does a similar thing with the placement of the rigid elements that are part of the system. Under the bigger module, a double flap can be observed which acts like a pocket. Under this part, the wiring can be put which makes contact with the ambiotex modules in the middle to make a full electrical circuit. This pocket concept which both these brands use protects the user from discomfort and keeps certain elements of the circuit in place. Noticeable is also the placement of the ambiotex system which is in the middle of the belly area.

Another brand that integrated technology and clothing is Pauline van Dongen. Remarkable is that she also integrated one of the more rigid modules on the side of the shirt. The capacitor which stores the energy is placed on the bottom right of the shirt as indicated in figure 33 (Pauline van Dongen, 2016, 02:10-02:18).

Also, the solar cells on the shirt are placed mainly on the sides of the shirt. Other than the sides these cells are rather placed all over the shoulders and back as well. The difference in the flexibility and thickness of the capacitor and the solar cells may be the cause of more freedom in the possible locations to place these elements on the shirt.

Figure 33: Locations of electronics in solar shirt

For a well-integrated energy harvesting system in clothing, the comfort of the user should also be considered. Apart from the user's comfort this factor is also important as the placement of the more rigid elements could also mean they could fail faster if placed on another location that does not support these more rigid elements. For this reason, an analysis is done for the products that are on the market already. After looking into the possible locations a map could be made with the locations that are frequently used. While this map shows the areas that can be used for the more rigid element of the system, more freedom for the placement can be achieved if these elements are flexible or thin.

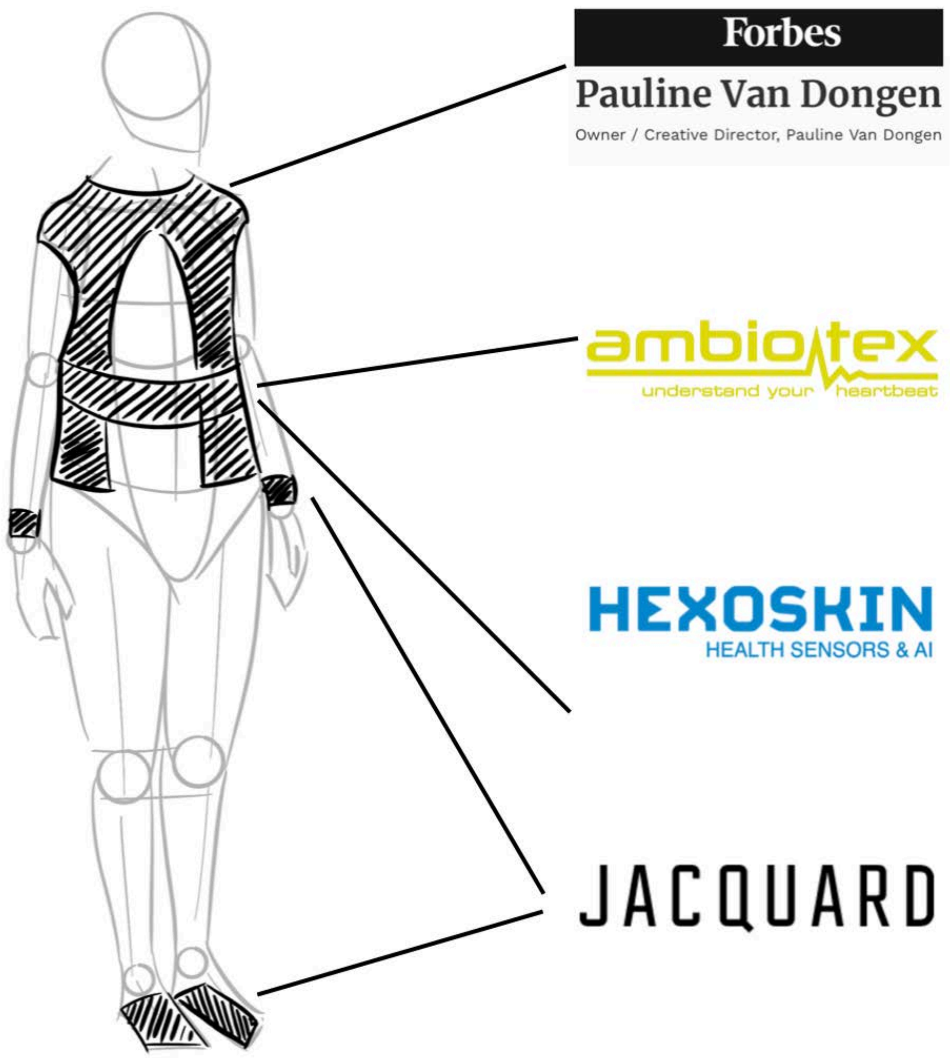


Figure 34: Locations of electronics within smart clothing

When incorporating more rigid elements an easy way to keep them in place and protect it would be to put a "pocket" design around it.

5. IDEATION

After the research phase decisions could be made for the execution of further processes. A framework for the design phase have been put up. Within these frameworks, the ideation will guide towards the final product.


Gallery
Layers
New group
New group
New group
New group
New group
Background colour

During the analysis chapter multiple criteria came up to define the framework in which this project would form itself. These criteria are listed again here.

- The energy harvesting modules that are to be used should be able to generate at least 130 mWh per day.

- The energy harvesting system should be able to withstand potential folding the clothes in which it is embedded.

- The energy harvesting elements should be kept in place after stretching the piece of clothing when putting the piece of clothing on.

- The energy harvesting system should be able to work after stretching the piece of clothing when putting the piece of clothing on.

- The energy harvesting module should function normally after a sitting position.

- The energy harvesting system should not be dangerous for the user after water damage occurs.

- The energy harvesting system should also be able to withstand the impact when the user has fallen.

- The energy harvesting element should not restrict the user with friction in a noticeable way so comfortability is not influenced.

- The product must withstand temperatures between -20 and 48 degrees Celsius.

- The product must withstand light rainfall, sweat and humidity.

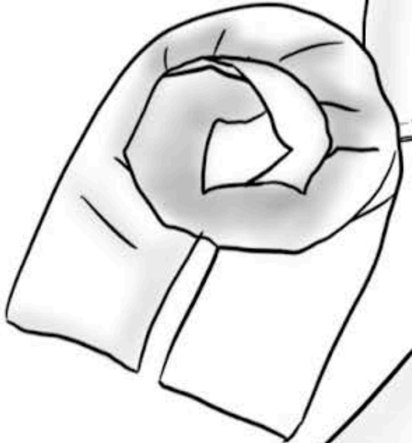
- The energy harvesting module needs to be able to be cleaned.

- The components of the energy harvesting system that have an electrical charge must not come in direct contact with the skin of the user.

- For the system a capacitor has to be integrated to store the energy generated by the energy harvesting element.

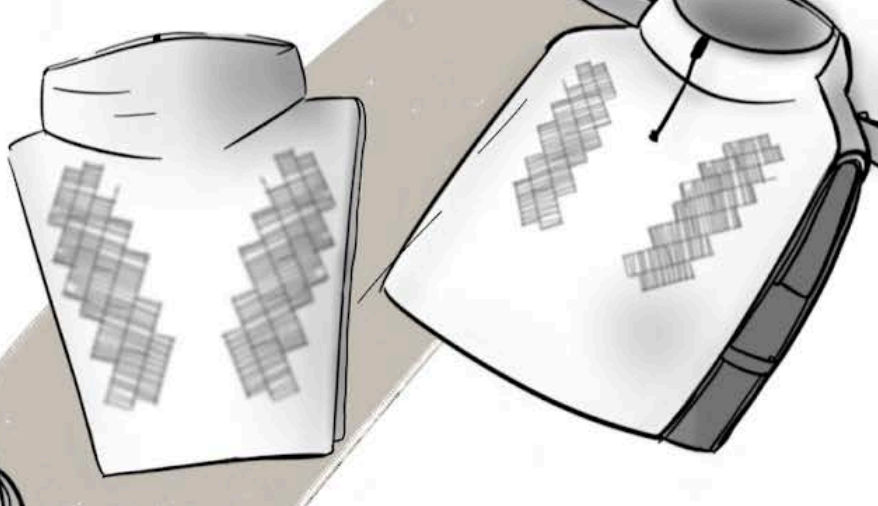
Jacket as carrier of the energy harvesting system as this piece of garment is used to go outside where the most energy can be harvested

Earlier designs used T-shirts as carriers of the solar cells

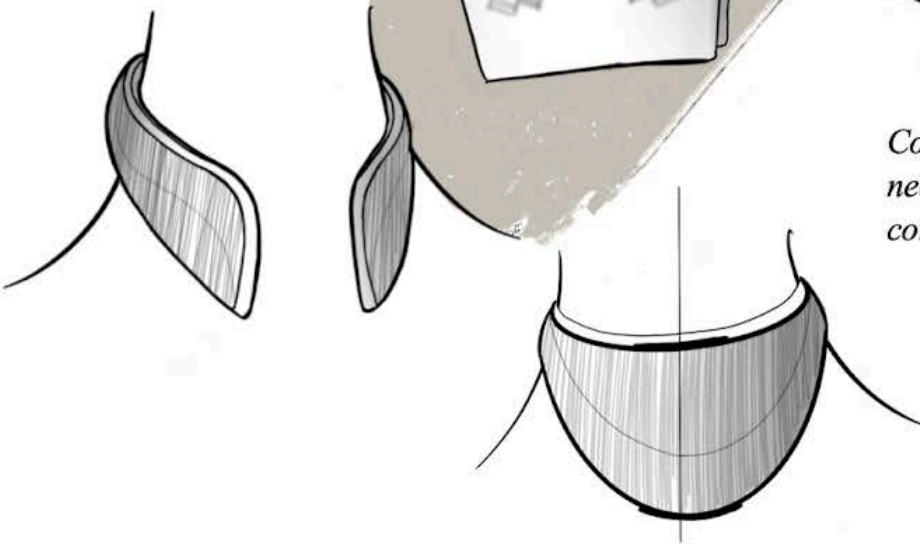


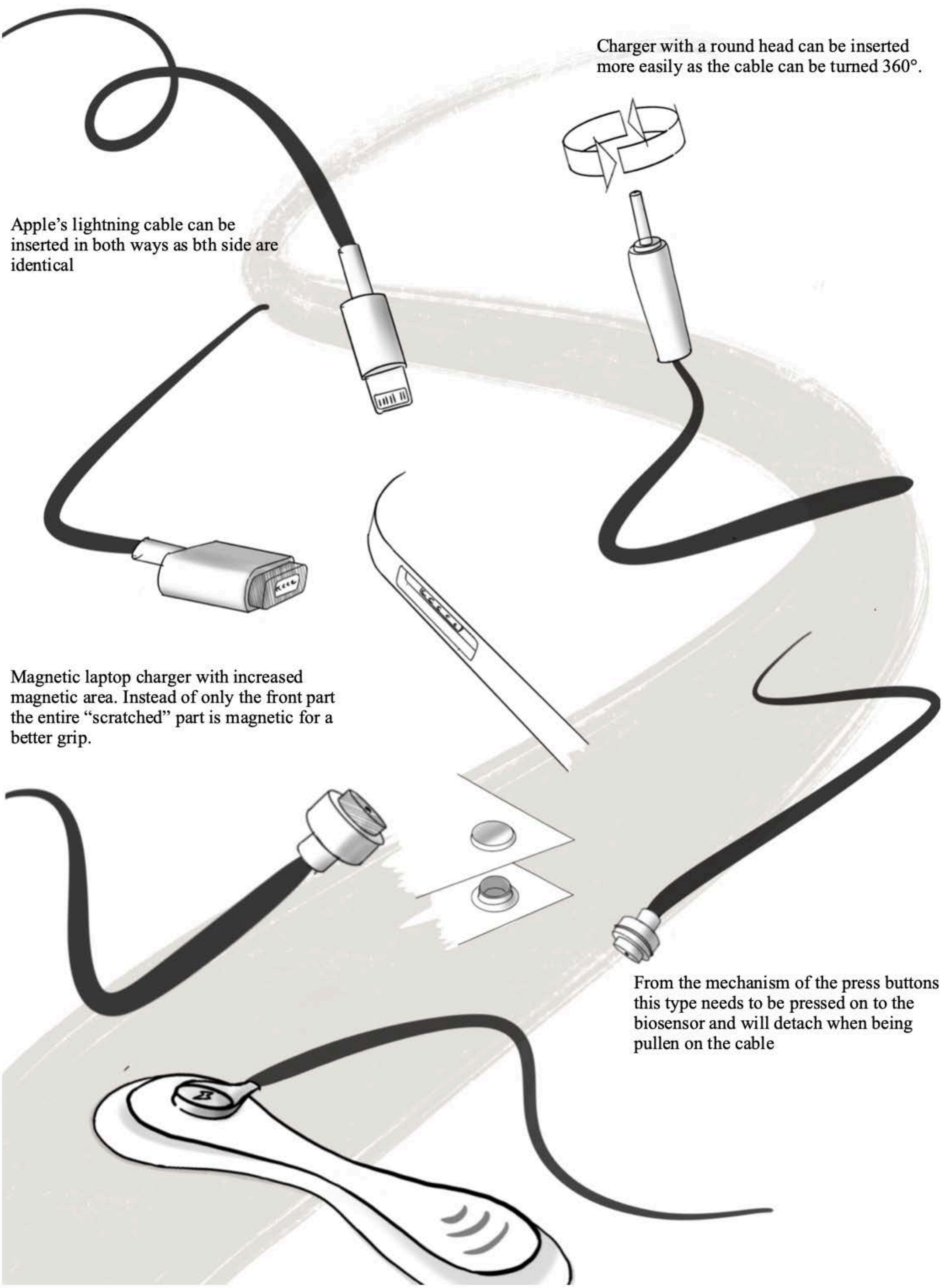
Scarves can be worn both inside and outside to keep generating energy in- and outside

Scarves can be worn both inside and outside to keep generating energy in- and outside



Collar that resembles the function of a necklace but with a softer textile feel to be combined with clothing




Charger with a round head can be inserted more easily as the cable can be turned 360°.
Apple's lightning cable can be inserted in both ways as bth side are identical
Magnetic laptop charger with increased magnetic area. Instead of only the front part the entire "scratched" part is magnetic for a better grip.
From the mechanism of the press buttons this type needs to be pressed on to the biosensor and will detach when being pullen on the cable

5.1 CONNECTION WITH BIOSENSOR

Connecting the energy harvesting element to the biosensor will provide this product with the needed energy.

The location where energy is stored should be part of the biosensor. If the piece of garment, on which the energy harvesting module is attached, is taken off later on the day the biosensor should still be able to work properly. However, as discussed a battery -in between the biosensor's battery and the energy harvesting method- will work as a way of securing the system. The placement of the battery in between the biosensor and the Solar panels would have a larger capacity of storing energy than the small zinc-air battery which is placed inside the biosensor. If the elderly might not feel like going outside one day the battery within the final product can still be worn inside with enough energy stored in the battery.

In order to connect the bigger battery to the zinc-air battery, a cable should be made through which the energy can be transported to the biosensor. The connection can be done in several ways of which each of the methods has its benefits.

The traditional cable like the ones commonly used for phones can be found with different heads according to the type of connection. These could be different kinds of USB types or other types like the lightning cable that is used for the iPhones. These types of cables need to be inserted in a special cavity in which the connection between the product and the cable can be made. When detaching the cable from the product the cable should be taken off in the same way that it is inserted. This causes a relatively strong bond between de cable and the product.

Currently, newer consumer products that are becoming more popular are wireless chargers. In order to charge the products, both the products and the charger need to facilitate the ability to wirelessly charge. This is done by integrating a coil in a certain architecture which creates a flux. Some of these wireless chargers are equipped with a magnet which “snaps” the product slightly into the right place. The placement of the coils for wireless charging also needs to be part of the biosensor which needs a complete restructure of the biosensor's internals.

In between these types of chargers, the combination of the traditional and the snapping one exists. Chargers that work with small magnets snap into place for connection with the product but can also safely be taken off without having to pull on the charger. The surface area of the magnet has been increased by not only making the front part magnetic but also the other sides that go into the slight cavity on the product. This ensures for better grip on the product.

For the application of the concepts, the latter is chosen to be integrated into the concepts. The use of the magnetic connector is designed in a way that it connects easily to the product. For the elderly this is useful. But there is another aspect which might be even more important. For the detachment of the cable this can easily be done as this connection easily detaches when a pressing or pulling movement is made, but when the cable is simply pulled due to a certain movement the charger keeps being attached.

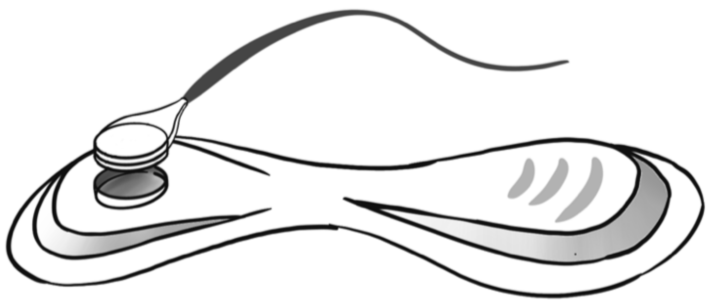


Figure 35: Biosensor with magnetic connector

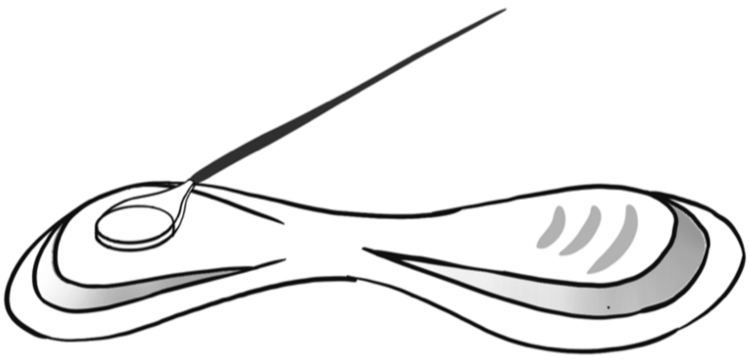


Figure 36: Biosensor with magnetic connector while the cable undergoes tension while keeping connection

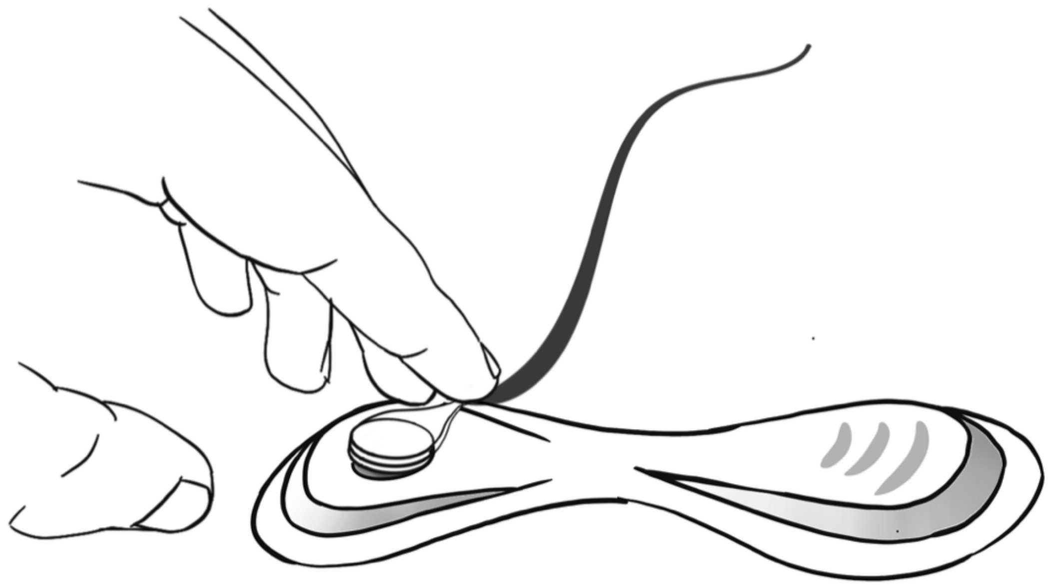


Figure 37: If the biosensor is pressed on the side so a tilted motion is made the surface area of the magnet partially disconnects from the biosensor and can be detached

5.2 SOLAR AND TEXTILES

Flexible solar cells are available in different shapes and sizes. The supply of these types of harvesters is large due to the high demand in these different forms. For the application with clothing, most of the developments are still ongoing.

The most flexible solar technologies that can be attained are the ones that are quite similar to the traditional type of solar panels that people know but flexible. The cells are placed in series according to the amount of voltage the panel should be able to deliver. In this example, the solar cells are sandwiched between textile layers and a layer of lamination.

While the development of flexible solar cells are still being worked on there are many variants that show huge potential for this project. One such example is the development of flexible solar cells that are integrated in between the weaving of the yarn. This example can seen in figure 38.

Figure 38: Solar cloth by Pauline van Dongen and Maaike Gottschal (oneworld.nl, 2020)

As most of these types of solar panels are still in their research phase these can not simply be implemented for this project's purposes. While the development of the new variants of solar cells is ongoing, the principle for this energy harvesting method would be the same. For this reason, other alternatives are used for the development of this energy harvesting system. This is done with flexible solar cells from SEEED and can be seen in figure 39.

Figure 39: flexible solar panel by SEEED

5.3 DESIGN DIRECTIONS

The earlier phases in which research was more important made this project's frameworks in terms of the design requirements. The requirements were both defined for the electrical system as that of the carrier in/on which this system would operate. After diverging and converging within the ideation phase 3 design directions could be presented. These products are presented identically and are still open for further iterations within this project, thus the name "design direction" rather than concept. Within each design direction, the locations of the electrical elements have been placed according to the earlier set criteria in the analysis phase.

The Directions all meet the criteria set earlier. However, after presenting the directions these will be methodologically evaluated with other criteria than the ones that earlier mentioned. These will be used to see the relative compatibility of each direction with the other.

CARRIERS OF THE SYSTEM

As solar cells have been chosen as the energy harvesting method they need to be implemented into a product that is exposed to the sun as much as possible. Earlier products like the Solar shirt by Pauline van Dongen have the solar panels embedded on the front and the back of the shirt, however, when most people go outside we should also consider the possibility that these cells will be covered by a jacket when the user will go outside.

Embedding the solar cells into a jacket or vest would be more logical as these are often worn when going outside. However, garments like jackets are only worn outside. While this should not necessarily be a problem it would be ideal to have garments that can be worn both in and outside.

Scarves can be worn both, in and outside depending on the thickness and the material of the scarf. As these items can be folded in a way that these are wider or less wide, so can the area that will be exposed to the sun.

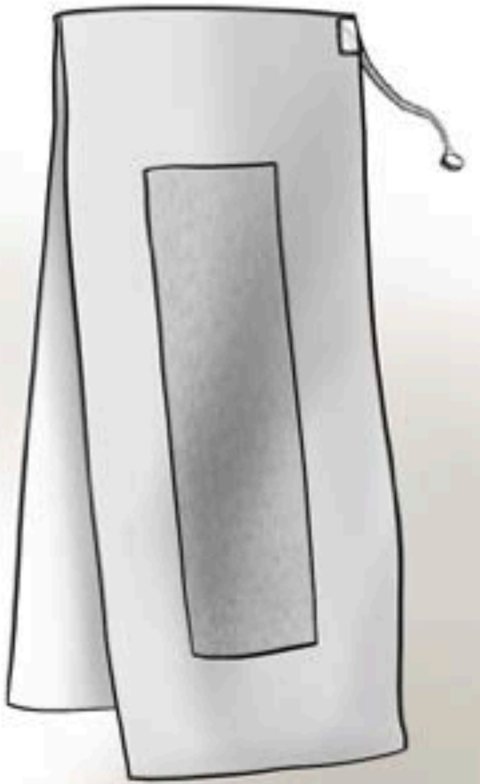
Making an iteration on the direction of a jacket a derivative of a bodywarmer can be generated. This direction describes a collar with pieces of excess fabric on both the chest and the back area. This can be worn over a simple T-shirt but also a thicket sweater or even a jacket.

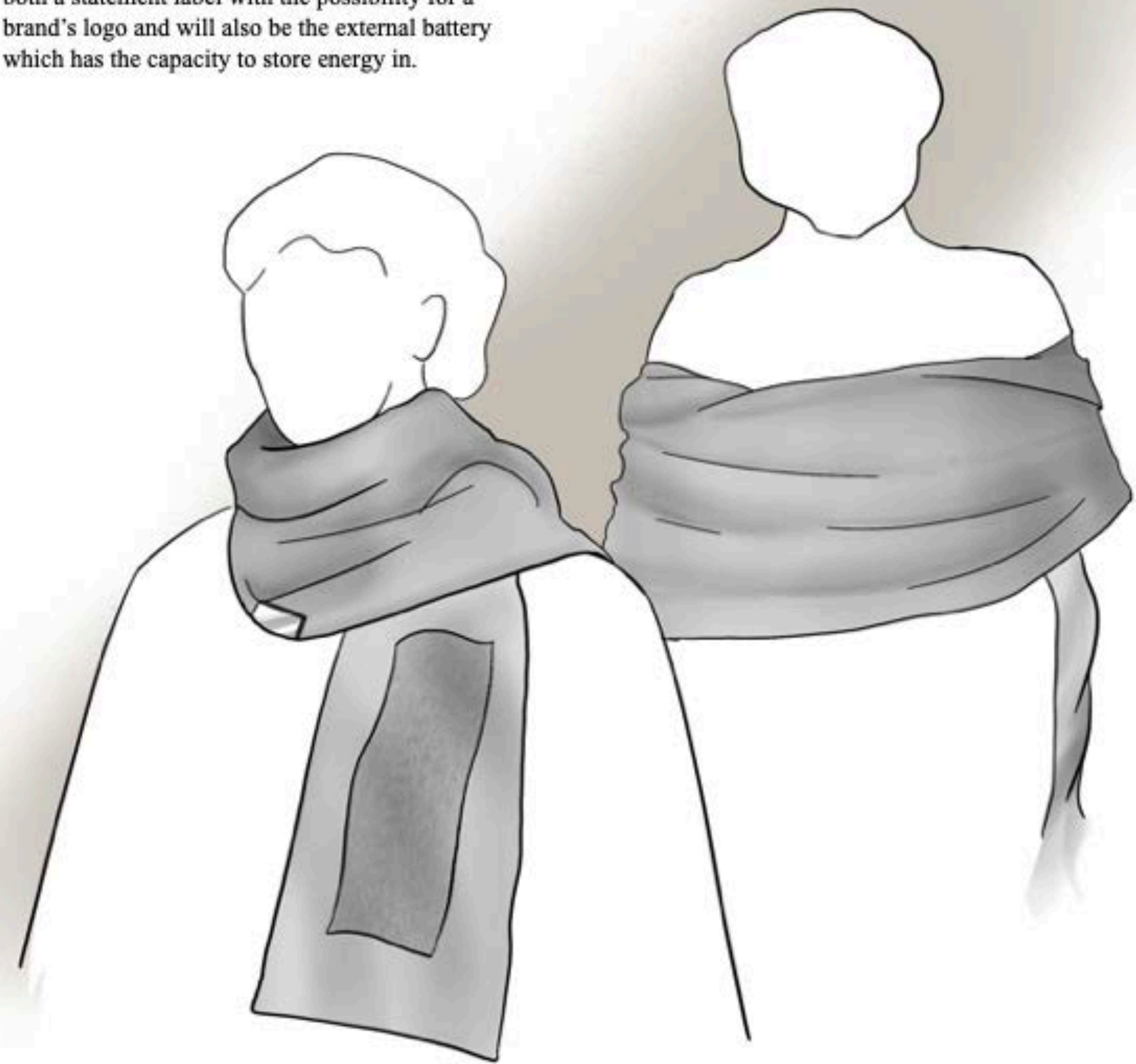
The last direction simulates a hybrid version of a collar and a necklace. While this product can be worn with every piece of "normal" clothing this direction shows the possibilities to wear this product with any other piece of clothing that the user may like. Making this product feel comfortable like all of the other clothing should depend on the ergonomics and the materials that are going to be used.

Solar Scarf

For this direction the concept shows the integration with a scarf. The Solar Scarf can be worn around the neck, head or shoulders for multiple purposes. Some of these purposes are warmth, sun protection or fashion.

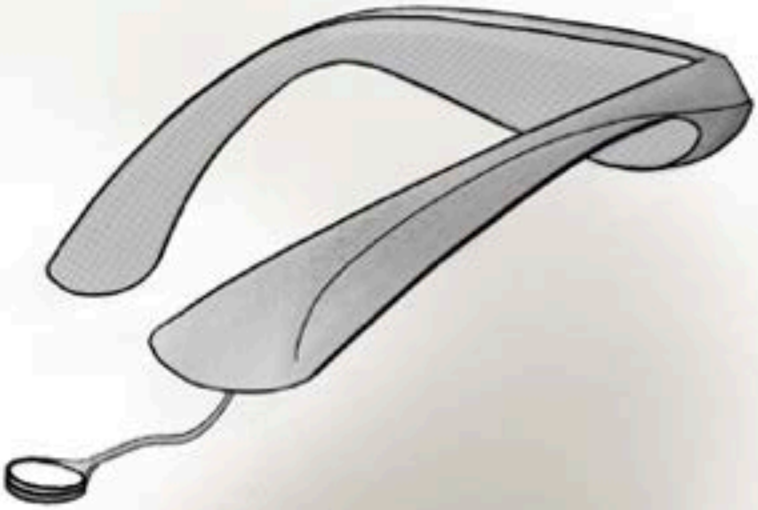
For this direction these functions are combined as the energy harvesting elements will generate energy through exposure on the sun. In order to integrate the solar cells, the scarf will consist of two layers in which the wiring will be placed in between these layers. The charger that will come out of the scarf will be in the middle as this can easily be connected to the biosensor. The small clipping on the scarf will be the only part which will be rigid on the scarf. This will function as both a statement label with the possibility for a brand's logo and will also be the external battery which has the capacity to store energy in.



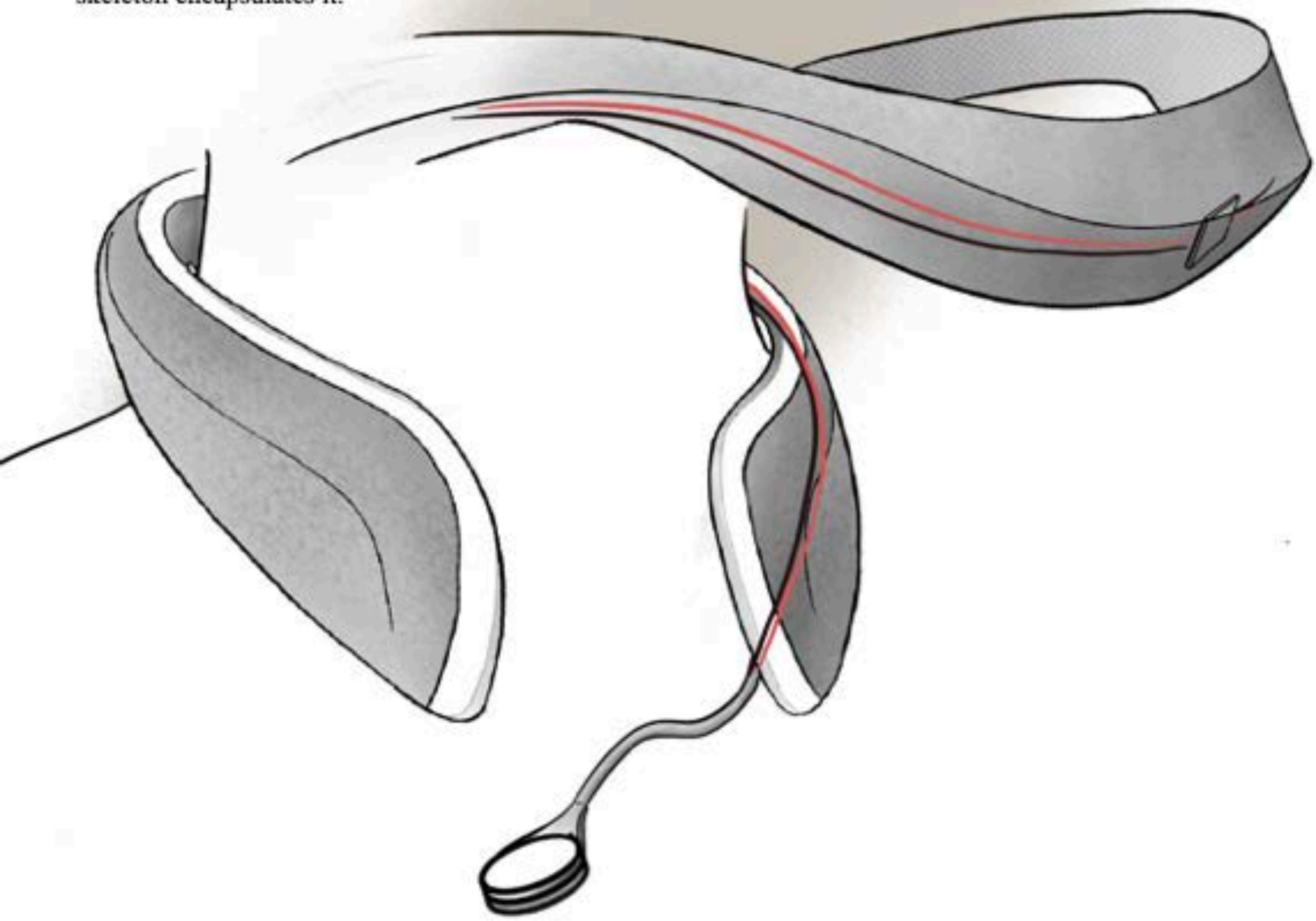


Solar Collar

The design of the Solar Collar is inspired by collars of a dress shirt. In order to create an ergonomic product for around the neck the products like wireless earphones are used. While the outside of the product consists of the flexible solar cells while the inner side will be a ventilating textile mesh. Putting this on the inside should make for a better comfort of the neck. The combination of these flexible solar cells and mesh are combined with an TPU skeleton. TPU is a flexible material which will bring this product as a whole all the benefits for energy harvesting without compromising with the fit and its performance.



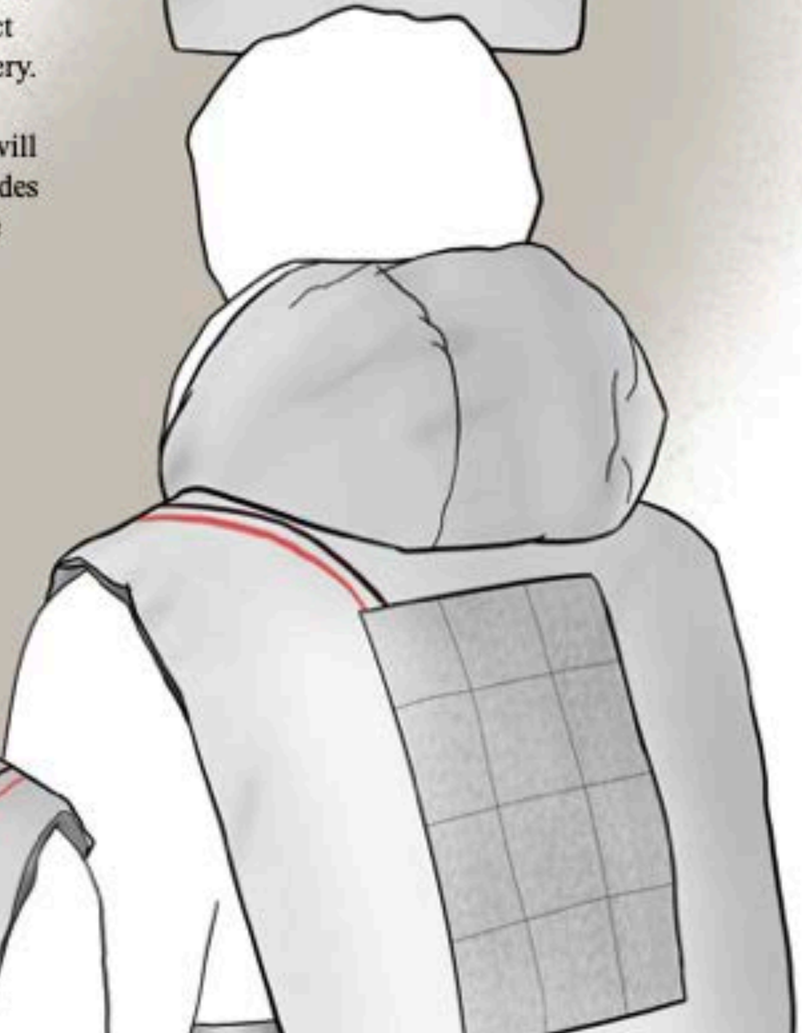
The outer layer consists of textile mesh and flexible solar cells the internals contains the battery and the wiring which can be connected to the biosensor. The wire coming out of the collar will be on the front left side which will be closest to the heart; where the biosensor is going to be placed. The external battery can also be placed within the product while the TPU skeleton encapsulates it.

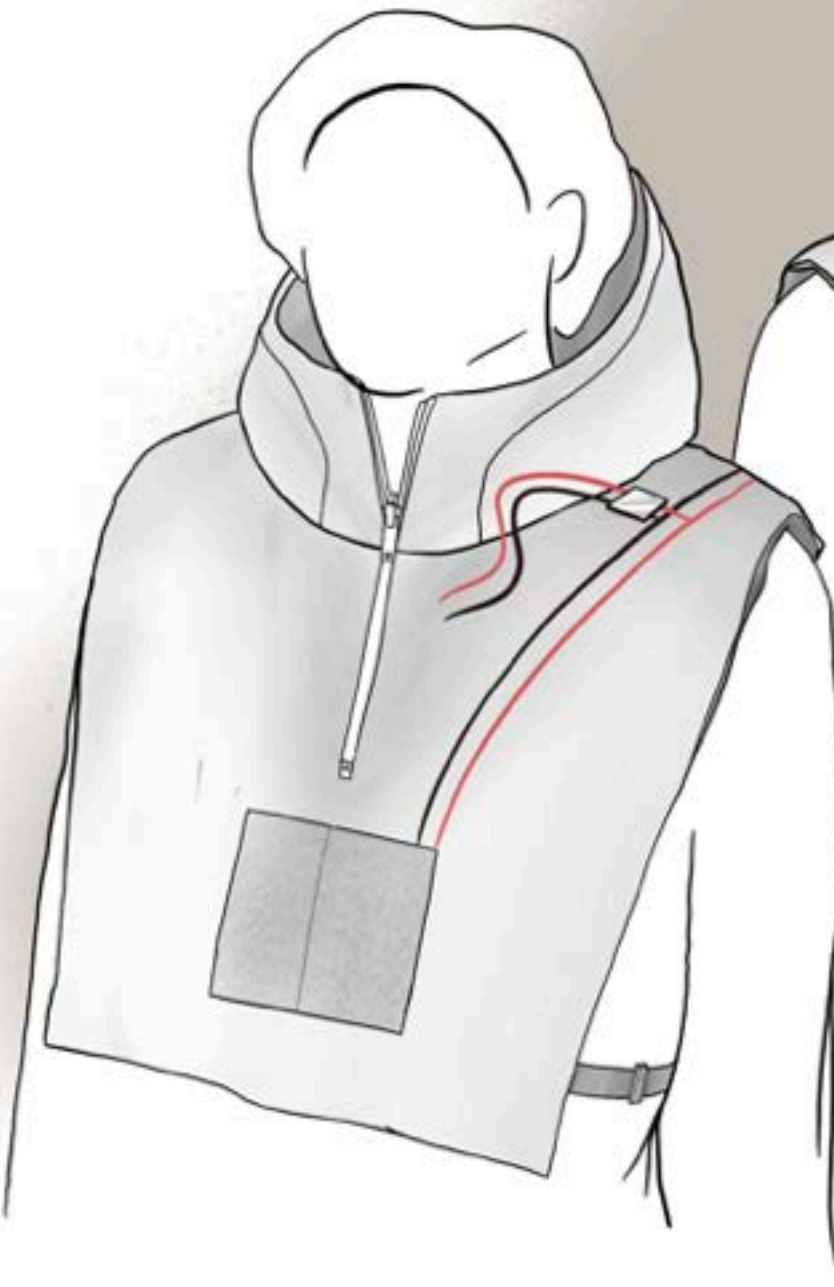


Hybrid Solar Vest

For this direction a sleeveless vest is made in a way that it can be worn over a layer of clothing. The vest will be slightly padded for comfort and warmth. Due to the design of the higher collar and the hood this vest is perfect for going outdoors. In order to make this item easy to put on the vest can be put on from the side as the straps on the side snap magnetically to each other. A zipper is also available in order to get the head though the opening more easily.

The flexible solar panel will be placed on the front and the back of the vest. When going outside this product can generate energy and store it on the external battery. The battery will be placed on the sides of the front. Because of the fit of the piece of clothing the sides will not have a tight fit to the body which makes these sides better suited to embed something more rigid like the external battery.





HARRIS PROFILE

In order to compare and evaluate the 3 different directions with each other the harris profile is used. The benefit of the harris profile is that this method provides a graphic representation of the strengths and weaknesses of the design concepts concerning the predefined design requirements. It can be used to evaluate these concepts and facilitate the ability to make well-considered decisions on which concept to continue with.

For the harris profile, the following criteria have been used to compare the different design directions with each other.

Detaching and reassembling the system to the biosensor. As the elderly generally have a smaller range of motion compared to younger people, the final product should be well adjusted to the target group. The easiness of connecting the energy harvesting system to the biosensor is important as this also determines the willingness of the target group to use this system.

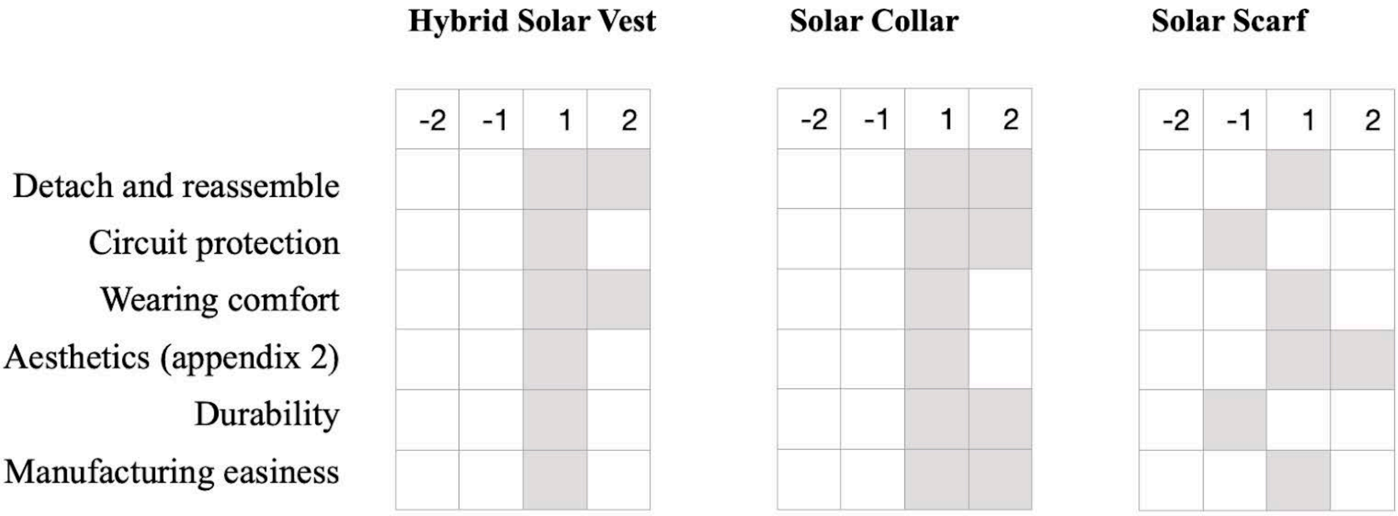
Circuit protection. If the circuit is susceptible to failure within the product this could also indicate the reliability of this product. The more components move, the more susceptible this circuit may be for failure.

Wearing comfort. These two works speak for themselves and show the relative comfort of the system to the other design directions.

Aesthetics. In order to determine the aesthetics of the different design directions, they were presented to the target group themselves. The people were asked to give a score to the proposed products. This way the desirability of the target group is taken into account as well.

Durability shows how durable this solution will be. Some products might have a longer or shorter lifespan due to the way they’re built.

Manufacturing ease provides an indication of how likely this product is to be developed. This also can indicate the relative production costs



According to the Harris profile the solar collar seems to be the best direction. If the person is wearing a turtleneck or vest the collar can still be put on the top layer so the product can harvest energy through the sun’s rays.

Through the survey with 15 elderly (Appendix 2) the Solar scarf seemed like the best direction. This was mentioned to be because it can easily be used by both men and women. The vest was given the lowest score as some mentioned this product to be more modern and “for younger people” the collar was also not given a middle score as it seemed also usable for both men and women. However compared to the scarf this product seemed less familiar than the scarf. The familiarity with the directions could form a basis on the choice for the target group which is the reason for the lower ranking of this criteria in the harris profile.

In order to make iterations on this product a prototype will be made to further enhance the crucial features to improve this product.

5. PROTOTYPING

Prototyping for the chosen direction needs to cover the form of the solar collar, the electrical circuit and it’s components. Creating a aesthetic and functional model would help validate design decisions and allow the design engineer to iterate by testing further with these prototypes.

6.1 FORM

FORM FINDING

The design process has been executed iteratively in order to finetune the final product more to the target group. Instead of virtually modeling the product and printing it more rapid prototypes were developed.
The very first model has been made with clay in order to validate the form with the earlier design direction drawings and the opinion of the elderly. However, the model was not able to function as a prototype for the form as it was not flexible and the weight difference with the concept would be too off. After this model broke new models were made.

These models were made from polystyrene (PS); In terms of the weight of the product, this would come close to the actual weight of the solar collar considering the materials that are going to be used. Also were they flexible enough to be put around the neck. The models were given their form through sanding so the model could be made smooth again for the target group to test the form's comfortably.

After making the first model it was proposed to the target group. The people of the target group could criticize the model on its ergonomic form. The feedback of multiple individuals was documented and used for the development of the next model (Appendix 3). The iterative process has been done five times which eventually resulted in a model of which the form was preferred the most. The final form has been curved more around the shoulders. This way the item will not stand in the user's way when turning their neck and will not feel like it's hanging on their neck but rather rests on their shoulders.

Figure 40: Polystyrene (PS) models

In the process of the iterative design phase of the prototype, the target group did mention the size to be an issue (Appendix 3). For model 1 and 3 the dimension of the neck orifice was chosen for a P95 person according to database DINED. This decision was initially made to make the product suitable for the majority.

However, approximately the mean size (P50) was used for the other prototype models on which the size was not mentioned as problematic.

While the product may suit many of the target group it may be important to also create the opportunity for the ones falling outside the spectrum in figure 41.

In order to facilitate a product that is suitable for people with different neck sizes, different sizes of the product should be offered. Even though the 5 people of the target group did not mention the last models to be too small, a slightly bigger size is advised to be produced too.

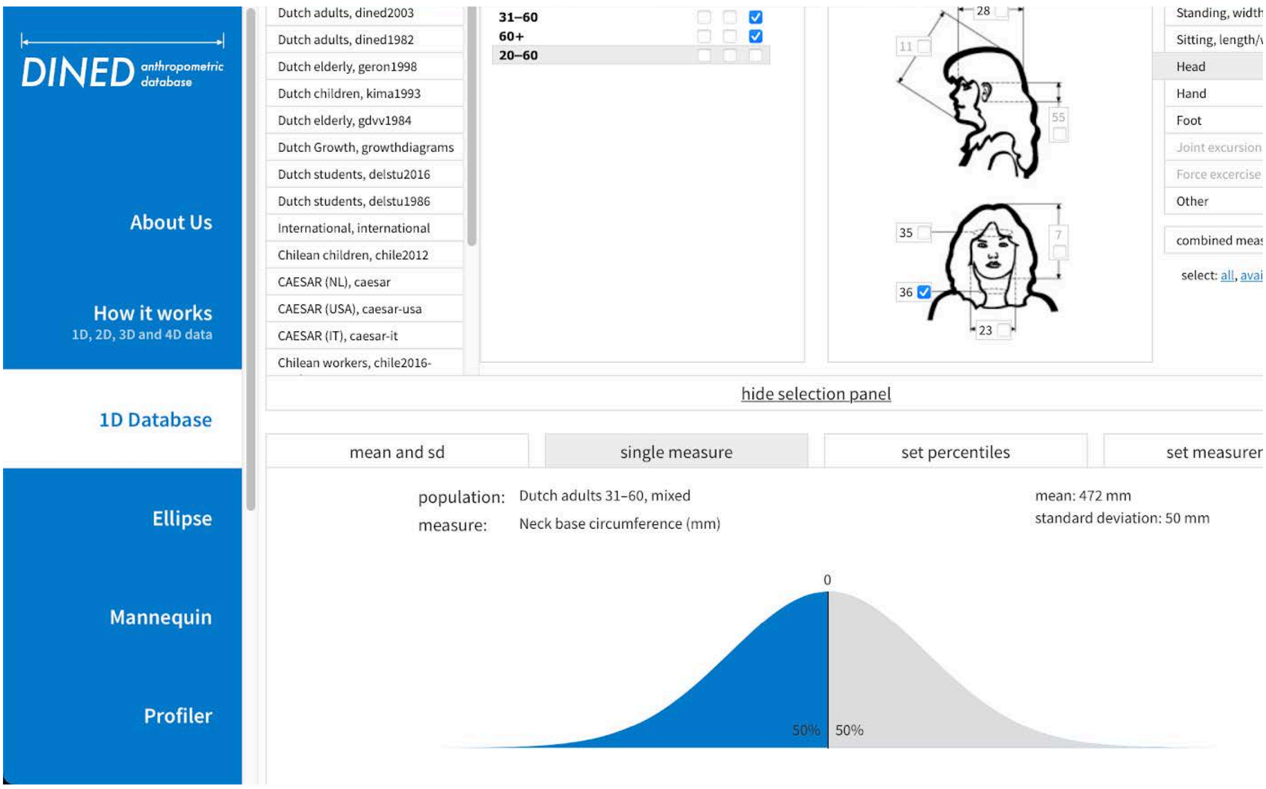


Figure 41: Dined Database for the neck circumference

6.2 THE ELECTRICAL CIRCUIT

For the very first test, a solar panel and a powerbank were used in order to validate the possibility to combine these elements. However, for this test, the pre-manufactured solar cells were used in which other components are embedded too to make the system work. The one used in the very first test is used to power a small motor.
If a circuit is to be built from the ground up a voltage regulator should be placed into the circuit too. In order to make this system work as efficiently as possible, the components and the solar panel's specifications should be properly adapted to each other.

SOLAR CELLS ON PRODUCT

Flexible solar cells are hard to get for consumers as the supply is relatively small and they tend to get out of stock very easily. The one acquired is from SEEED studio. The panel is shown in figure 42. The panel consists of 12 cells that are connected in series in the way as indicated by figure 42 by the red and black line. The solar panel's specs are to provide a maximum of 5V and 5W in which the current would be 1A.

As the solar collar does not completely have the area available as that of the solar panel, the panel size needs to be adjusted. If a smaller solar cell is used this model can be cut along the individual cells. Approximately half of the panel's cells can fit on the solar collar the panel would still mean that the cells together could provide 2,5 V and 2,5 W.

In order to divide the solar panel into 2 pieces, it could be cut precisely in between the 12 cells. Solar cells are polarity sensitive. This means that the two ends of the series of cells need to be connected the right way or the cells will not function as they should. To do so a red and black cable has been used to indicate which will be the positive end and which will function as the negative end. Thin cables similar to those which were already used on the panel are soldered on the metal wire which is already sandwiched between the layers connecting the cells with each other. Afterward a dot of hot glue has been used to keep the wires, solder, and the backside of the flexible solar panel together which should prevent the connection from easily breaking.

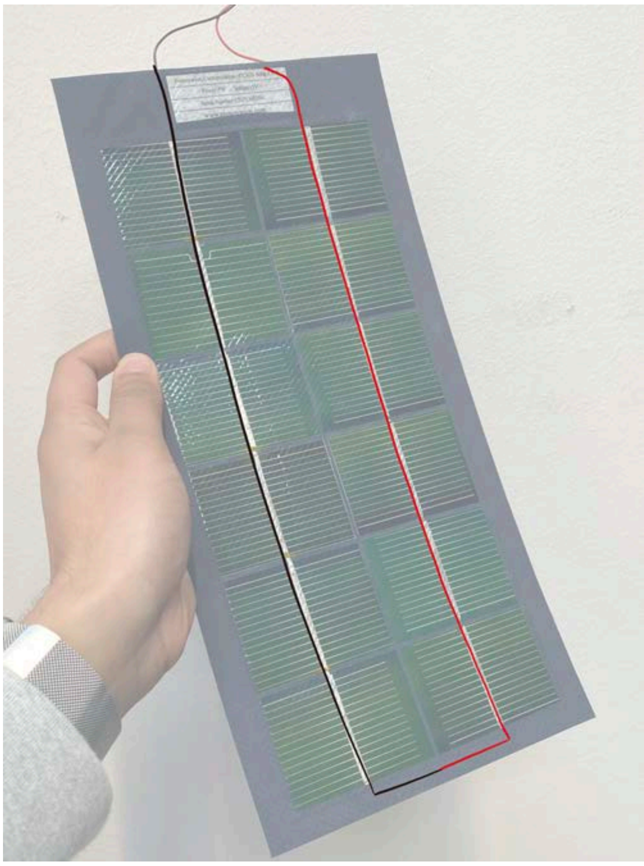


Figure 42: Conductive line connecting the individual cells within the flexible solar panel

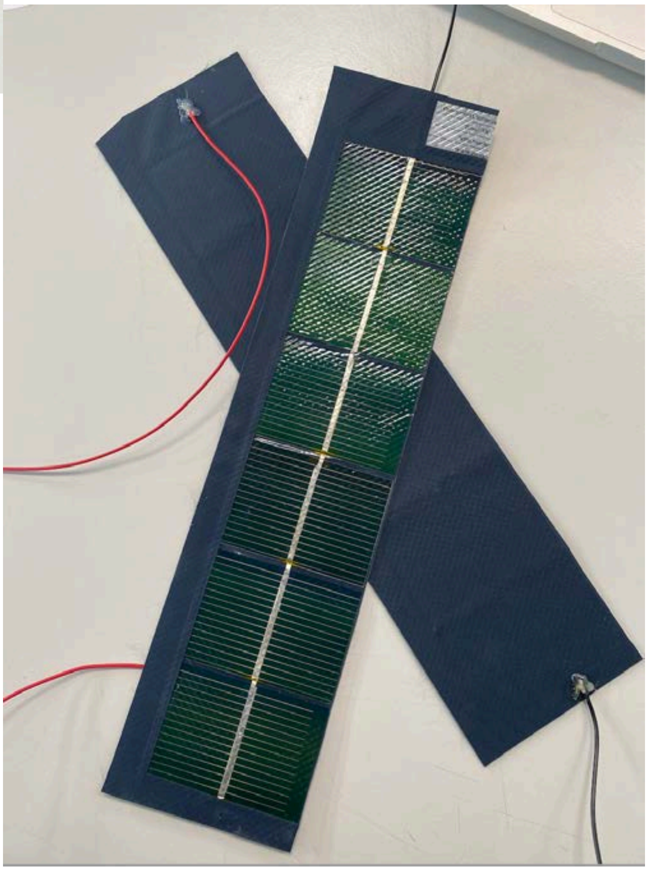


Figure 43: Divided solar panels for the prototype

BATTERY

The capacitor that is going to be placed in the product will act as a buffer for when the battery inside the biosensor is empty. For reference, the battery of the apple watch is used as an example for implementation in the solar collar as well. The apple watch's battery is flat, lightweight, and able to store enough energy for the biosensor to work multiple days. The battery of the Apple watch appears to hold 1,1 Wh of energy. This amount of energy can be translated to (1100 mWh/65 mWh/d) 16,9 days of the biosensor working on only the external battery. The user of this product may be able to use the solar collar for 16,9 days after one day of fully charging the external battery.

However, the battery of the watch can not simply be used for the prototype. The battery used in the apple watch is a LiPo cell which requires a specially designed charging circuit. These are made with the use of specialized chips. Which makes the product more complicated for the time span of this project to cover.

According to Ing. Verwaal from the TU Delft, the matching of the solar cell's purpose and the battery is extremely important to make optimum use of the solar cell. For this reason, the battery voltage for the external battery is chosen in which this is similar to the expected voltage output of the solar panel. A battery that is less demanding for a connection to the circuit would be the Nickel-metal hybrid (NiMH) battery.

The battery specifications are chosen to fit with the maximum power point (MPP) of the solar panel which can be fitted on the collar. For this reason, the battery will have a battery voltage of 2,4 V and a battery capacity of 0,75 Wh which is ⅔ of the apple watch's capacity. This means that theoretically, the battery could store (16,9*0,666) 11,3 days worth of energy within this battery.

CALCULATION:

1100 mWh / 65 mWh/d = 16,9 days

verhouding apple watch battery en huidige battery:
1,1 Wh/ 0,75 Wh = 0,6666

0,6666 16,9 days= 11,3 days*

BIOSENSOR

While the actual Philips biosensor could not be used for the test of this project the energy demand of this product can easily be simulated. The energy drainage by the biosensor should be the same as that of the substitution in the model. This will be done with the use of a resistance. In order to simulate the energy use of the biosensor the current needs to be calculated so that the resistance in ohm can be acquired.
The biosensor works on a 1,5 V battery and uses 65,25 mWh per day. Meaning that the biosensor's power demand is (65,25/24=) 2,7 mW.
Using the following formula: P= U*I can be used to derive the current which is (0,0027/1,5=) 0,0018 A.
Using this outcome for the calculation of the resistance can be done with the formula U=I*R.
Filling in this formula will give (1,5/0,0018=) 833,33 Ω

Initially, a visual indicator would be embedded which proves the system is able to supply the biosensor with the needed energy but the ability to verify the precise values of the currency and voltage going through the wires would give a better evaluation of the system's proof of concept. For this reason, the LED is left out and a meter is placed at various places in the circuit for the exact values.

CONNECTION

As flexible solar panels were hard to get your hands on for this prototype the circuit had to be built around the solar panel that was managed to be ordered. This way the proof of concept could be created. The following circuit was made to optimally supply the system with the needed energy.

The circuit in figure 44 shows a structure in which all components are embedded which are needed for an efficient system. In order to explain the circuit in a more understandable way the following diagram is made in figure 45.

The structure starts on the left with the flexible solar panel and ends on the right with the biosensor. The solar panel can generate 2,5V and 2,5W while in the light sun.
Directly after the solar panel and on two other locations in the circuit small capacitors are placed. These capacitors are used in order to keep the system more in balance. The capacitors catch the highs and lows of the solar panel's voltage output. This may occur when a shadow falls upon the solar panels. By catching these peaks and lows of the output they keep the biosensor and the voltage regulators from having to endure these instabilities. The capacitors' energy consumption can be neglected as it is relatively low.
The voltage regulators are the components that make the solar panel, external battery, and biosensor work together. As the voltage output of the solar panel is variable the voltage regulator makes sure that this voltage is converted to a voltage that is better for the external battery or the biosensor. The first voltage regulator has an input of 1,5-6V while the output is set to 2,4V. This would make this voltage work well with the external battery which is placed directly after this regulator. Another function of the regulator is that they also function as a diode. A diode makes sure that electrons are only able to transport in a one-way direction. This circuit prevents the solar panel from tapping energy from the external battery.
After this regulator, another regulator is placed which converts the voltage from 2,4 to 1,5 volts which can then be used by the biosensor.

The arrows which are shown in the figure show the way the energy may flow to. At the external battery, the arrows go both ways. The generated energy from the solar panel can be used to be stored in the external battery or can be used to power the biosensor's battery. According to the energy demand, the energy will flow there where the circuit requires it the most. If the biosensor is not full this will be charged first, otherwise, the external battery will be charged. If the solar panel does not provide enough energy the external battery's capacity will be used to charge the biosensor's internal battery.

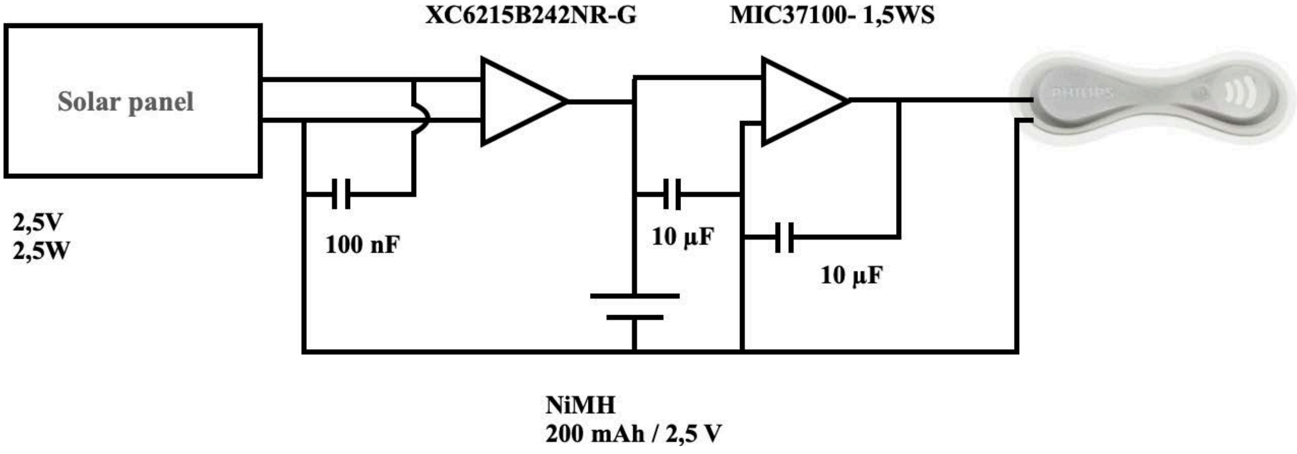


Figure 44: Electric circuit for prototype

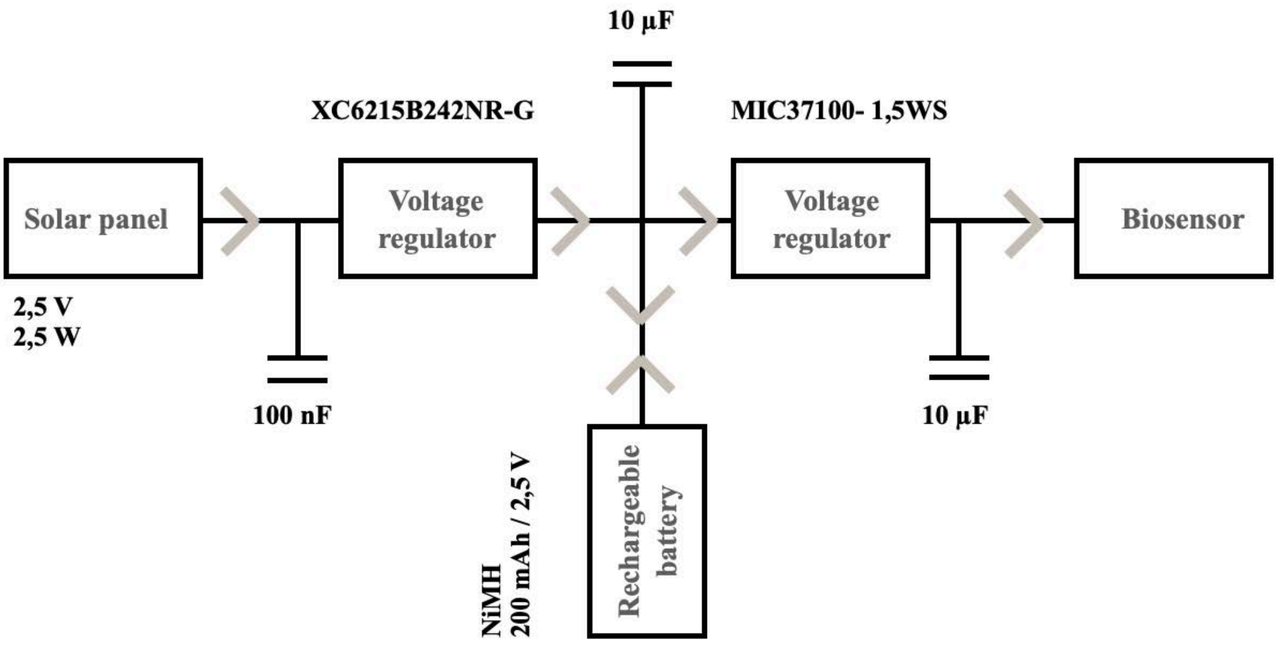


Figure 45: Power diagram

7. TESTING

Prototyping for the chosen direction needs to cover the form of the solar collar, the electrical circuit and it’s components. Creating an aesthetic and functional model would help validate design decisions and allow the design engineer to iterate by testing further with these prototypes.


LIGHT METER
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DESIGNED FOR RECYCLING

7.1 SYSTEM AND THE BIOSENSOR

During the prototyping stage, the form of the collar has been made by making iterations in terms of design. This has been done after each of the models that were made. This resulted in the styrofoam model that is used in the following tests.
To validate the product as a whole the connection with the biosensor should also be tested. For this, the solar collar has been presented to two people of the target group in order to evaluate the ability to work with this product as intended whilst designing.

During the test, the elderly were explained in detail how the solar collar is supposed to make sure the biosensor is always provided with the needed energy. They were explained how the collar should preferably be worn every time they go outside or at least once every 4 days as the battery of the biosensor could then be completely discharged. First, they were asked how likely it would be for them to actually go outside with this product. Afterward, they were asked how the connection from the collar to the biosensor is experienced and how this may need to change.
For the cable connection to the biosensor, they were shown how the cable would be attached to the collar and how it would magnetically connect to the place on the biosensor. For this, the Apple MacBook's MagSafe charger has been shown to demonstrate the way the magnetic sides would connect to each other. After this, the participants were shown different sizes of the magnetic head that is to be connected with the biosensor. These can be seen in figure 47.

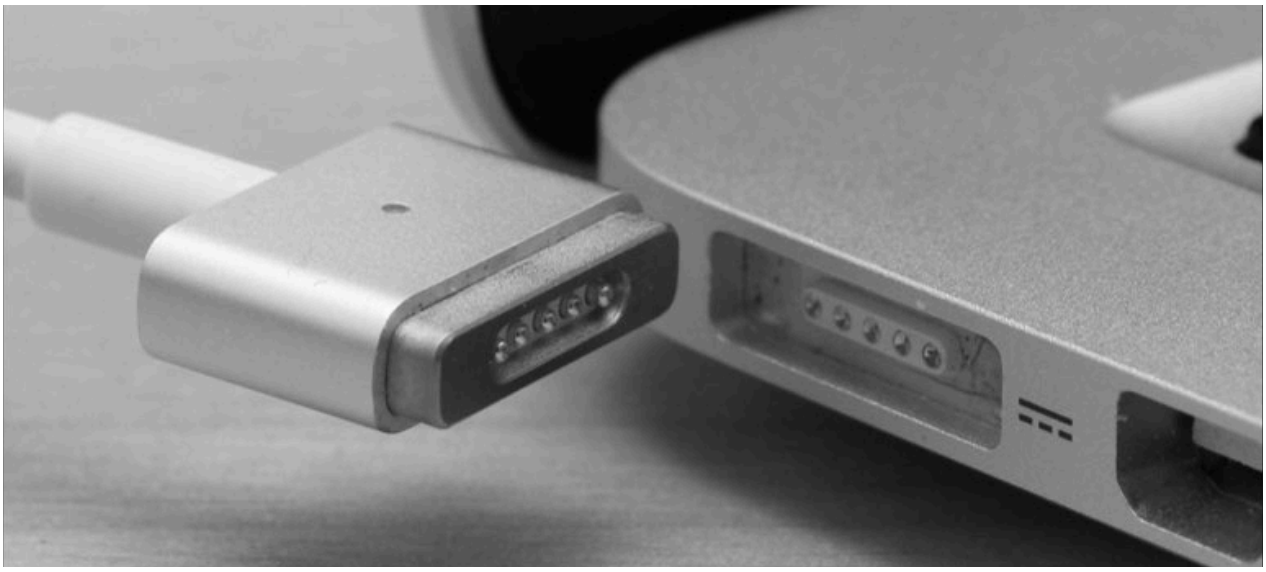


Figure 46: Apple MagSafe Charger

Figure 47: Three sizes for the connector that is to be places on the biosensor

The connector that was preferred the most was the smallest one for both participants. Although this size seemed small, the participants thought it was not necessary to make this connector bigger. They were able to put the connector on the biosensor without complications. One of the participants stated that the bigger connectors could become an irritation because they are bulkier.
While conducting this part of the test they both mentioned they would preferably look into the mirror when wearing the solar collar. It would be easier to connect the cable with the biosensor and the collar can be adjusted so that it would sit nicely.

Both the participants stated that connecting the cable would not be a problem in terms of complexibility and comfort. However, it would be nicer if the cable length could be adjusted instead of one certain length of the cable coming out of the collar. For this, the participant proposed the cable to be pushed back into the collar instead of one length hanging from the collar. An iteration can be made with the principle of a measuring tape which can be retracted with the use of a spring mechanism. This way the cable can be pulled out of the collar if more length is desired. Otherwise, the cable can be pushed back on the orifice in which it comes out. An iteration of this can be seen in figure 49 in which the mechanism of a retractable spring cable mechanism has been embedded in the product. This mechanism can be found too in retractable measuring tapes or ski pass holders. For this mechanism the cable retracts itself when pulled out entirely.

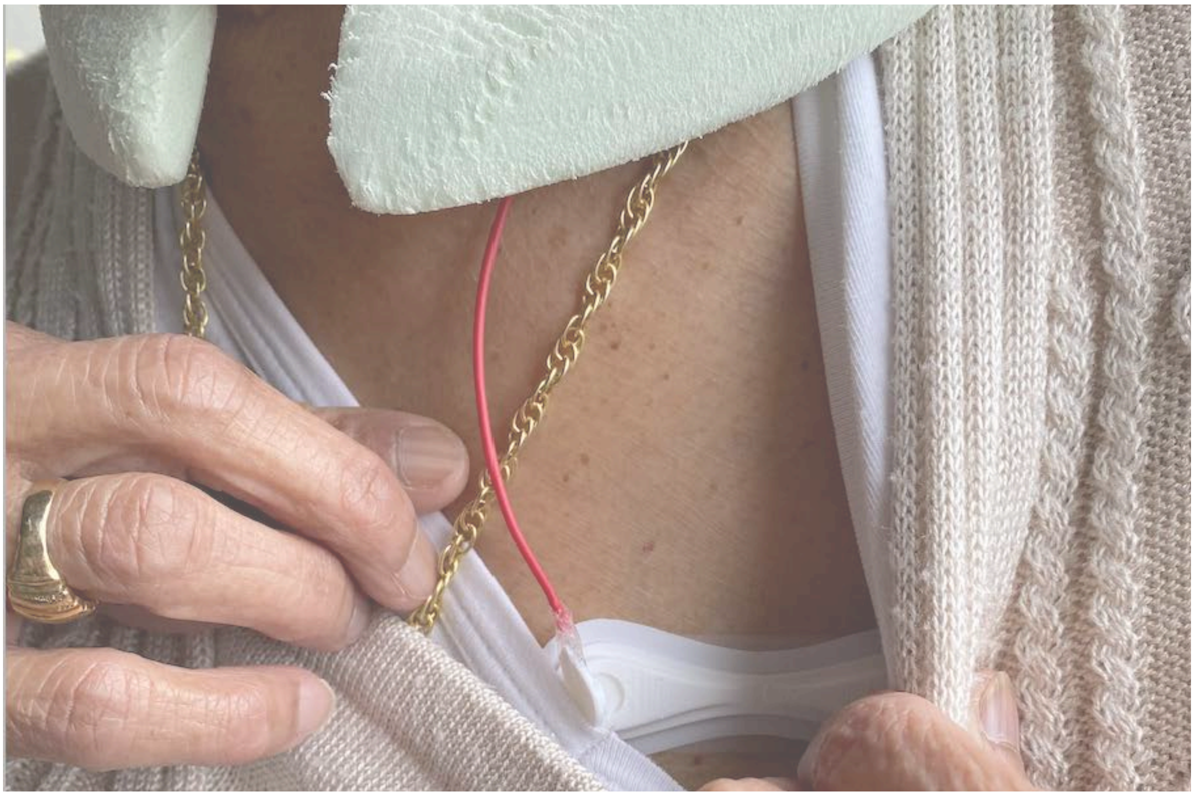


Figure 48: A moment in the user test with the connectors

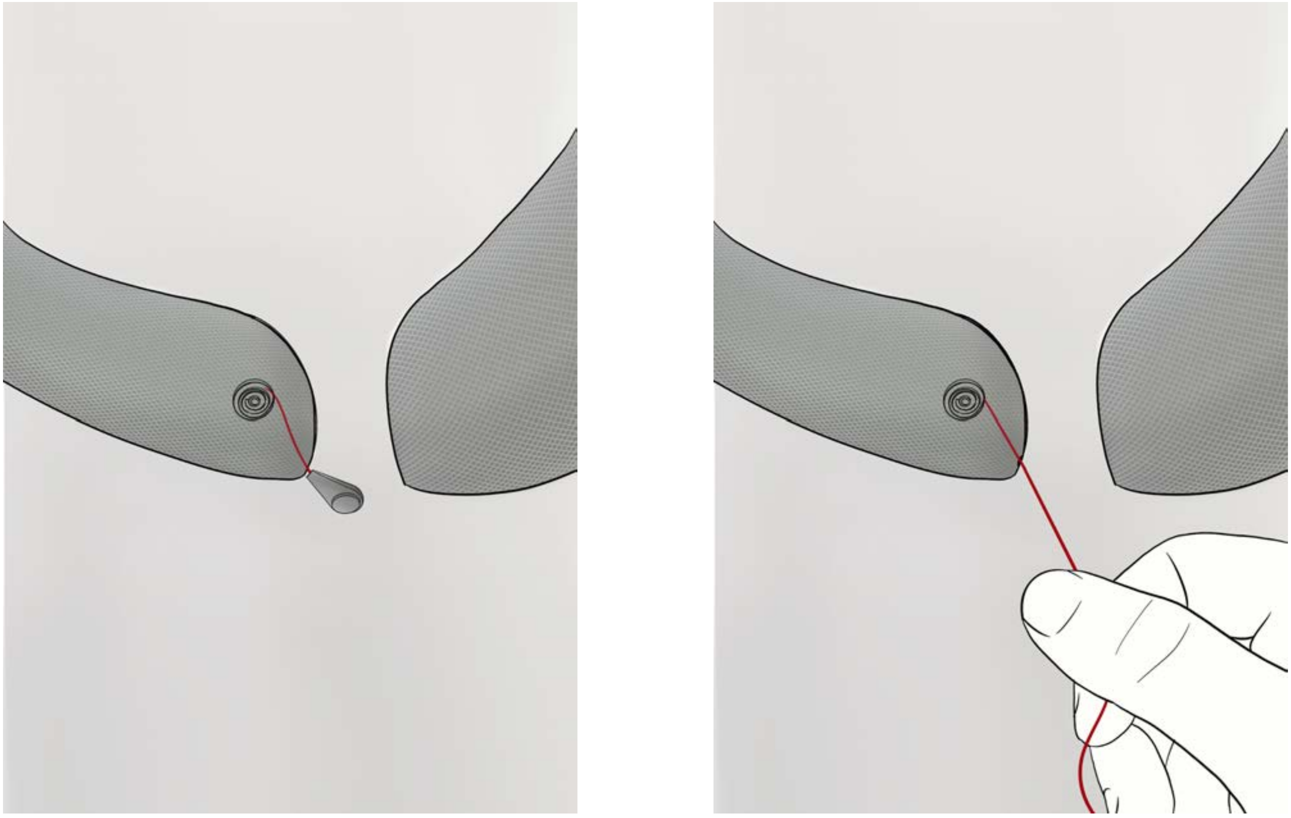


Figure 49: use of a spring mechanism within the left side of the solar collar for a variable length of the cable

CONCLUSION:

The length of the cable to the biosensor should be adjustable. This could be done with the use of The cable being able to be pushed back into the collar or pulled out of it when more length is needed.

SCENARIO

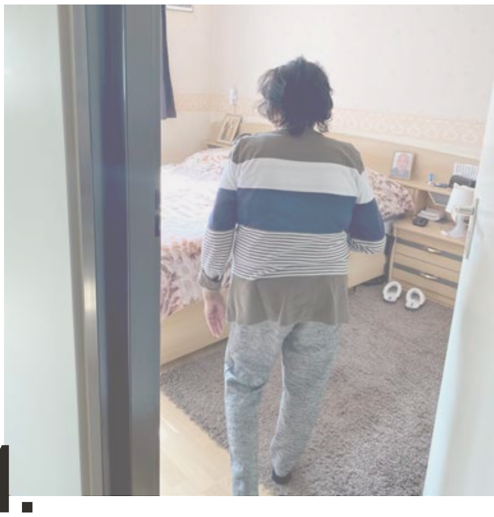
After this part of the test a more complete user experience test is executed; for one of the participants, the entirety of a day was reenacted in several moments with the product. She could also give input whenever she thought it was necessary. In order to gain valuable insights from this test, the principles of the mom-test have been kept in mind. The participants are asked little questions. If they are asked something the focus lies on the participants rather than the product. The key is to listen and observe more and try to get the most objective perspective on your potential solution.

1. In this scenario, we started in the morning in which the target group woke up. After taking a shower the participant of this target group goes back to her room to get changed.

2. She does her morning ritual which consists of some face creams, perfume, and hair products. When doing so she mentioned she had to be careful with the biosensor. If the biosensor would detach she would like to have the possibility to replace the sticker herself so that it would not become an issue once it will not stick anymore. Here she mentioned that this could also be a problem when she took a shower. It is also possible that the biosensor would detach in the bathroom or the participant would like to take off the biosensor herself and only wear it during the day. If this last was the scenario she stated that the biosensor would be placed on her day cream or near her other daily products so she has everything in place.

3. After this part of her morning routine, she makes breakfast and after that, she sweeps her house. The participant did not make any negative remarks while doing these tasks. She mentioned that the biosensor is not an issue on the chest.

4. Early in the afternoon she usually goes outside for a walk after which she usually gets some small groceries. For this, she grabs a bag for her groceries.


1.


2.


3.

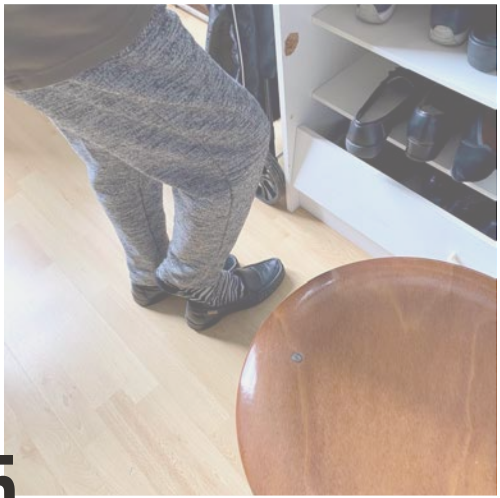

4.

5. Most of the shoes she has are loafers in which no laces need to be tightened. She mentioned that there are no issues with the biosensor as well. Sometimes she does use a long shoe lift to get in her shoes more easily but that too should not be an issue with the products that are to be designed.

6. The solar collar is placed near other items which are used to go outside. A facemask, disinfection gel, some scarves, and her jackets/vests are here. Now that the weather is getting nicer a sweater would suffice. If there would be more wind a scarf or vest with a higher collar would be used. This would be used under the solar collar so that sun rays would still hit the product.

7. The solar collar is put on. The participant took the model and opened the gap between the two ends a little more to slide the collar on her neck from the back. She stands in front of a mirror in order to connect the cable of the solar collar with the biosensor.

8. Connecting the cable head with the biosensor is mentioned to not be a problem when done in front of a mirror. The cable length is mentioned to be preferred to be variable so that the product would look neater.



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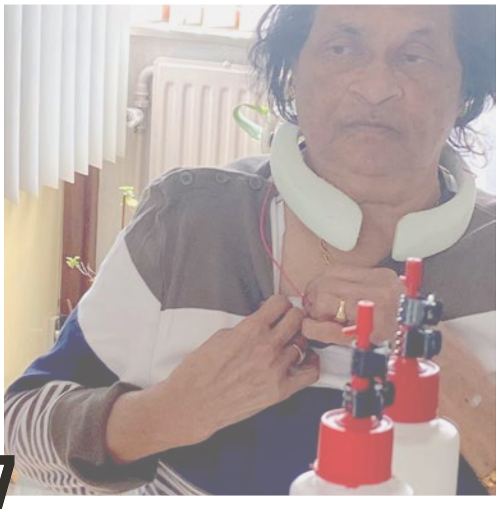

7.

8.

5. Most of the shoes she has are loafers in which no laces need to be tightened. She mentioned that there are no issues with the biosensor as well. Sometimes she does use a long shoe lift to get in her shoes more easily but that too should not be an issue with the products that are to be designed.

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8. Connecting the cable head with the biosensor is mentioned to not be a problem when done in front of a mirror. The cable length is mentioned to be preferred to be variable so that the product would look neater.

CONCLUSION:

It is also possible that the biosensor would detach in the bathroom therefore the participant would like to be able to take off the biosensor and put it back on by herself.

During the development of the solar collar the general assumption was made that the solar collar could be worn anytime as soon as the biosensor would demand more energy. However, after the scenario was created for this prototype specifically it is likely that the participant of this research will only wear the solar collar when she goes outside.


9.


10.


11.


12.

7.2 EFFICIENCY

In order to validate the values of the circuit, a multimeter is attached to specific points in the circuit. Together with these values, the light intensity is measured with the use of a light meter.
As the weather is variable and can show significant changes from day to day. The light intensity meter will be able to quantify how much light there was at the moment of conducting the tests. By including this data the reader gets a more accurate representation of the conditions in which the following values are measured.

The data in figure 50 indicated in which conditions the energy input for the battery and the biosensor is sufficient. Conditions 1,2 and 3 are all conducted outside. The outcomes of these different conditions are all similar as the battery and the biosensor can be supplied with the needed energy. Even when the solar panel is outside in complete shade it is able to provide enough energy for the system. This means that the solar collar is able to charge the biosensor or charge the external battery whenever the user wears it outside.

The tests of the system in indoor conditions show less optimal measurements. Although condition number 5 still allows the system to charge the biosensor, the other conditions are not able to generate enough energy for any of the two. Condition 5 shows that wearing the collar near a window in the sun would support the system to charge the biosensor's battery. Charging the external battery will not be able due to the low voltage which is supposed to be 2,4 to charge the battery.

Condition number 6 and 7 both do not provide enough energy to charge the biosensor nor the external battery inside the solar collar.

CONCLUSION:

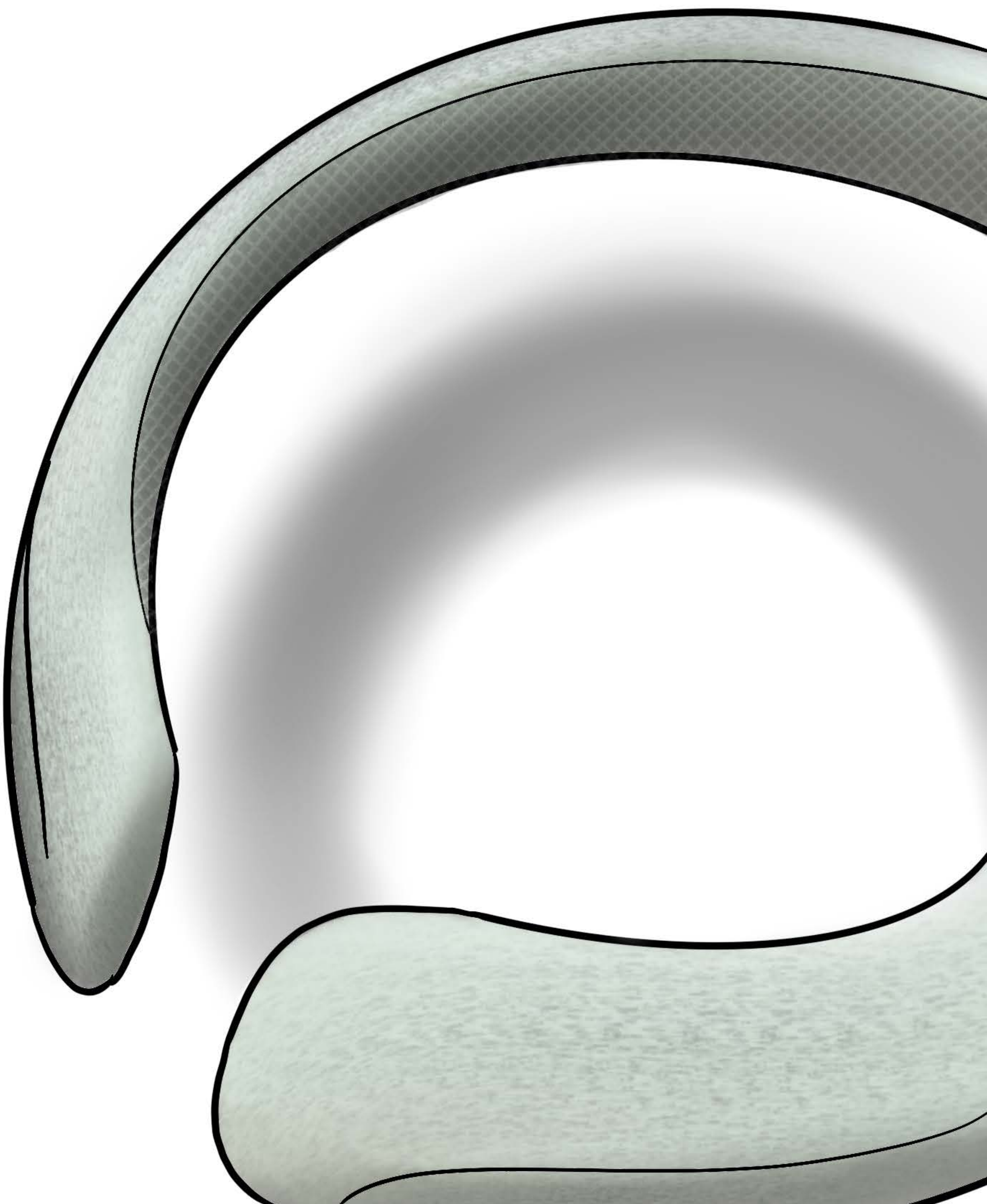
The conditions which all took place outdoors seem like the most efficient ones for the solar collar to operate in. Even in the shadow the solar collar is able to charge both the biosensor and the external battery.

Condition	Light intensity (LUX)	Solar panel output (V)	Solar panel output (A)	Voltage input Biosensor (V)	Voltage input external battery (V)
#1 Outdoors; in full sun	~35000	3,5	0,4	1,5	2,5
#2 Outdoors; with half panel in shade	~35000	2,6	0,2	1,5	2,5
#3 Outdoors; completely in shade	~4500	2,2	0,06	1,5	2,5
#4 Indoors; near window in sun	~8000	2,4	0,10	1,5	2,4
#5 Indoors; near window in sun; half of the panel in shade	~8000	2	0.5	1,5	1,7
#6 Indoors; near window; in shade	~2100	1,3	0.02	0,7	1,3
#7 Indoors; 4 meters from a window	~750	0,5	0	0	0,5

Figure 50: Value measurements in multiple conditions

8. CONCEPT ELABORATION

In this chapter the concept's features will be more elaborated on. The findings from testing both the aesthetic and functional model will be translated to recommendations for the continuation of the final product's development.



8.1 SOLAR CELLS

The innovation on solar energy harvesting is ongoing and at the moment multiple instances are researching the possibilities to create more efficient cells. In order to create a product that is more future-proof, possibilities for future implementations are made thus also initiating viability for this project's solution.

The solar cells used for the prototypes are not the most optimal ones that can be used for this purpose. The current prototype will be able to power both the external battery and the biosensor's battery when used outside or indoors near a window. However, when the product is improved with other cells which are more efficient the possibilities of the product can be made that theoretically, the batteries will never run out of energy or even produce more power which can be used for more purposes than this project covers.

Figure 51: InfinityPV Solar Tape

Dr. Marie Chae at the TU delft currently got a Ph.D. degree in Clothing and Textiles from Yonsei University in Seoul, South Korea. Marie has published articles on flexible solar textiles and received awards from the Korean Society of Clothing and Textiles. Chae introduced another type of solar cell which she was using for research.

In figure 51 the solar cells can be seen which Chae was using. These are the so-called thin-film solar cells. The possibilities with these types of cells are promising due to the lightweight, flexibility, and thin form. These cells are not yet able to be used for the solar collar; it is a matter of time for these types of cells to be efficient enough to be used for more purposes than they can now.
She also mentioned the development of the third generation of solar cells being in development right now. The most produced third-generation solar cells are the dye-sensitized solar cells. “Dye-sensitized solar cells (DSSC) are based on dye molecules between electrodes.” (Tawheed Kibria, Ahammed, Mahmud Sony, & Hossain, in press, pp. 1–3).
Chae has too been working on the development of the DSSC. The benefits of these types of innovations have another benefit than the performance. Due to the dyes, different colors of the solar panels can be produced. These also benefit the aesthetics as the entire solar collar is going to be covered by these panels, mentioned Chae. In chapter 8.4 the potential colors for the solar collar are discussed.

Chae stated that these third-generation cells will have the best performance, could be used for aesthetic purposes, and are going to have a significantly better environmental impact compared to the solar cells that are currently available.

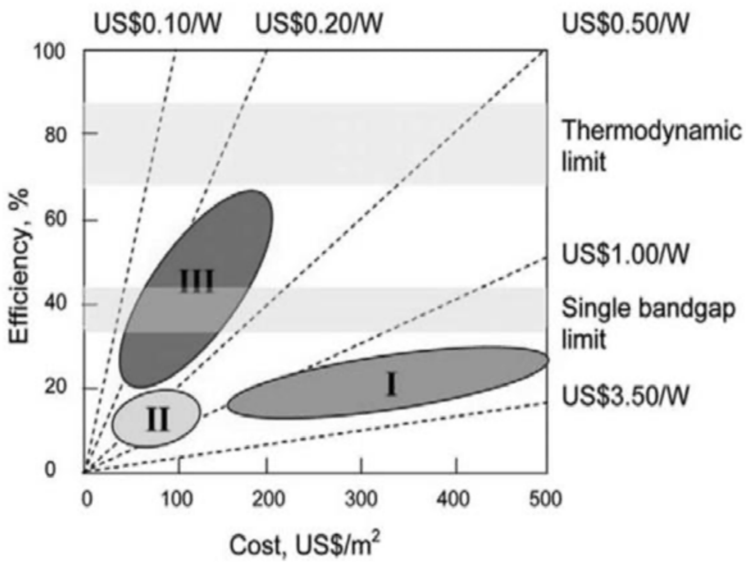


Figure 52: Price vs efficiency among the different generation’s solar cells

8.2 BATTERY

LITHIUM POLYMER BATTERY

During the prototyping phase, a capacitor was embedded for the system to be able to store the energy. For this prototype, a NiMH battery is used. An alternative to this type of battery would be the LiPo battery which is also commonly used in certain products. A reason to choose these types of batteries would be the energy density which is significantly higher than those of the NiMH batteries. One example is the apple watch which needs to be as thin as possible.
The placement of the battery into a product would therefore mean that the weight and the volume of the battery can be relatively low compared to the battery used in the prototype.

If a LiPo battery is used for the final product the system's architecture will change drastically in order to facilitate the specific (dis-)charge voltages. For this, a circuit is made.

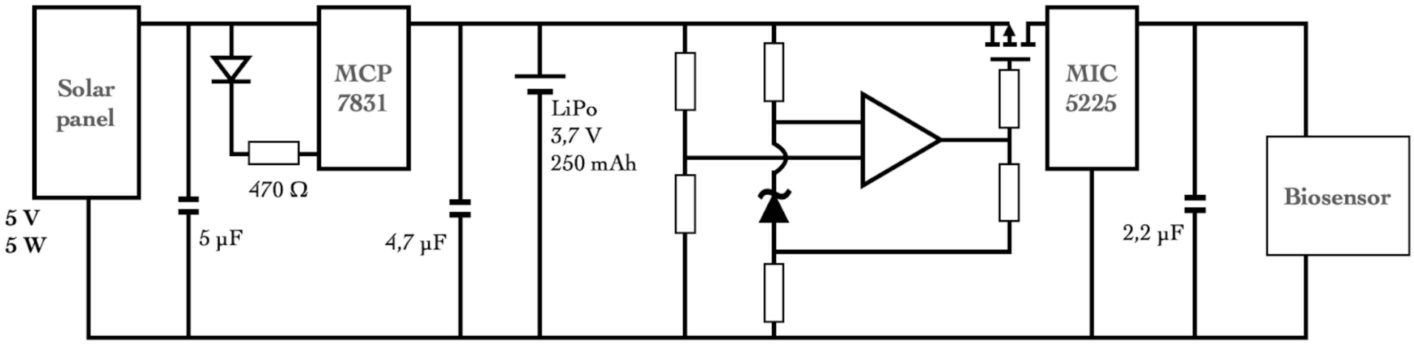


Figure 53: Circuit for Lithium polymer battery

In figure 53 a circuit is made for the LiPo battery. In this circuit an ultralow power, precision undervoltage-lockout circuit is also embedded. The circuit monitors the LiPo battery's voltage and creates a disconnection of the load to keep the battery from deep discharge. This mechanism will activate whenever the battery voltage drops below the lockout threshold.
According to Lee (n.d.) “If a battery is discharged below the recommended end-of-discharge voltage, overall battery performance degrades, the cycle life is shortened and the battery may die prematurely. In contrast, if the lockout voltage is set too high, maximum battery capacity is not realized”.

The circuit is designed for a solar panel that can generate 5V and 5W. If these are changed due to the different solar panel specifications on the market the components need to be changed accordingly. If the product is to be designed with a LiPo battery the foundation of the circuit should be used and the components should be connected as illustrated in figure 53.

THE ELECTRICAL CIRCUIT

In chapter 7.2 the circuit is tested in various conditions. If the solar collar is used outdoors, or indoors near a window, the system is able to work properly. The amperage provided by the solar panel is also validated by T. Soerdien, an electrotechnical engineer at Riscure. However, the demand of the external battery might fluctuate due to its state.
The charging current of the biosensor and the external battery depends on the situation. Soerdien stated that the one extreme situation might cause trouble. In the case where the external battery is completely drained the first few hours all generated energy is directed to the external battery within the solar collar itself. Therefore it will not be able to power the biosensor immediately when used.

CONCLUSION:

In this situation, the solar collar needs to be put near the window on a sunny day so the battery within the solar collar will be able to charge itself. To keep this situation from happening the electrical circuit should include an indicator that gives a signal whenever the solar collar’s battery is drained to a certain point. This could be done by including a visual indicator like a micro-LED.

8.3 PRODUCT DETAILS

SIZES

In chapter 6 the sizes of the solar collar needed to be determined in order to create a physical prototype. The orifice of the prototype was made according to the mean neck base circumference. For the tests with 5 participants (Appendix 3), the chosen orifice seemed to fit perfectly. For some participants, the collar was bigger than for others but they all stated to be completely satisfied with the fit. This is also due to the flexibility of the solar collar.

In order to determine another size for the solar collar, the dined database has been utilized. Since the current model fits many of the target group, even though the neck base circumference of the users may differentiate a little, the size for P90 could be used for the second size. For this orifice, the circumference increases to 536 mm. The difference from the smaller size would be approximately 1-1,5x the standard deviation. Together with the flexible characteristics of the solar collar the bigger size should work for those of the target group who won’t fit the smaller size.

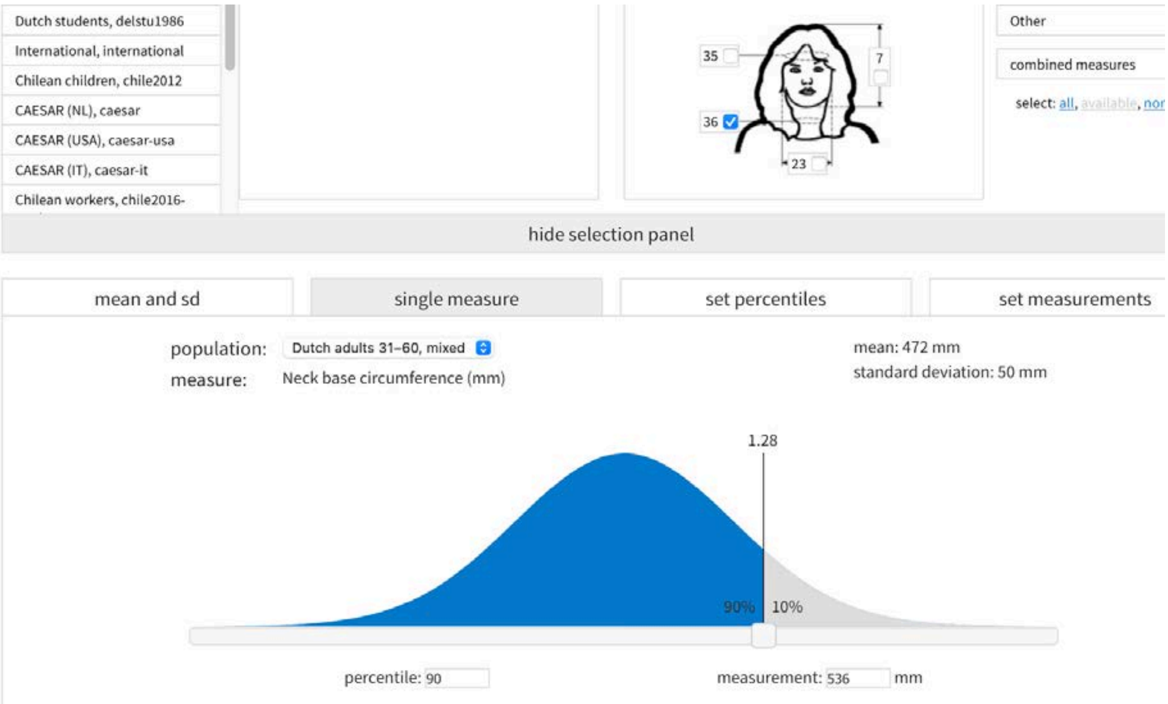


Figure 54: Dined data for standard deviation

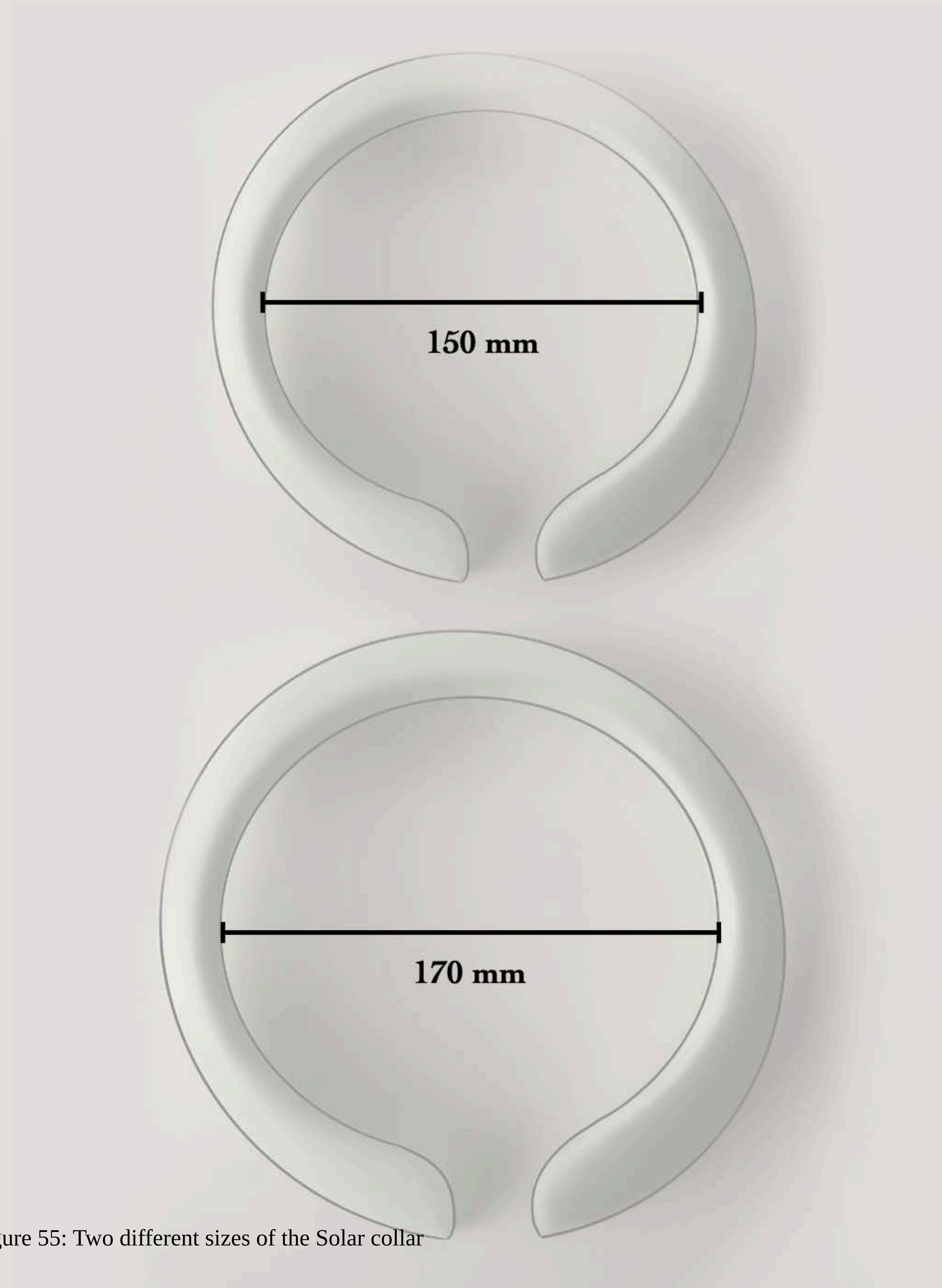


Figure 55: Two different sizes of the Solar collar

MATERIALS

Textile mesh

Flexibel solar cells on the outside


PCB
Spring mechanism for
retractable cable
Textile mesh
Battery

Cavity for placement of
internal components

TPU housing covered
by solar cells

The solar collar needs to be placed around the neck therefore a material should be chosen which is not entirely rigid. A material that follows the movements of the user while still maintaining its given form. In order to find the right material, Dr. Ir. E. Tempelman has been consulted. Tempelman has been teaching both the bachelor and master students of industrial design engineering about materials and production for years and also published a book about Manufacturing and Design.

Thermoplastic Polyurethane (TPU) was mentioned to be one of the suited materials. The material is commonly used for transparent phone cases, in the automotive industry, and even in footwear. These appliances of this material indicate the toughness of this material.

The benefits of TPU are its high resistance to abrasion and its high elasticity, and can easily be colored.

The production of this material can be done through injection molding. The benefit of this process is the high accuracy in the product's dimensions.

For the inner side of the solar collar, the textile mesh is placed together with filling for a cushion-like aesthetic and feel. Both the mesh and the filling are to be made from polyester so that this will be able to clean with the use of a wet wipe.

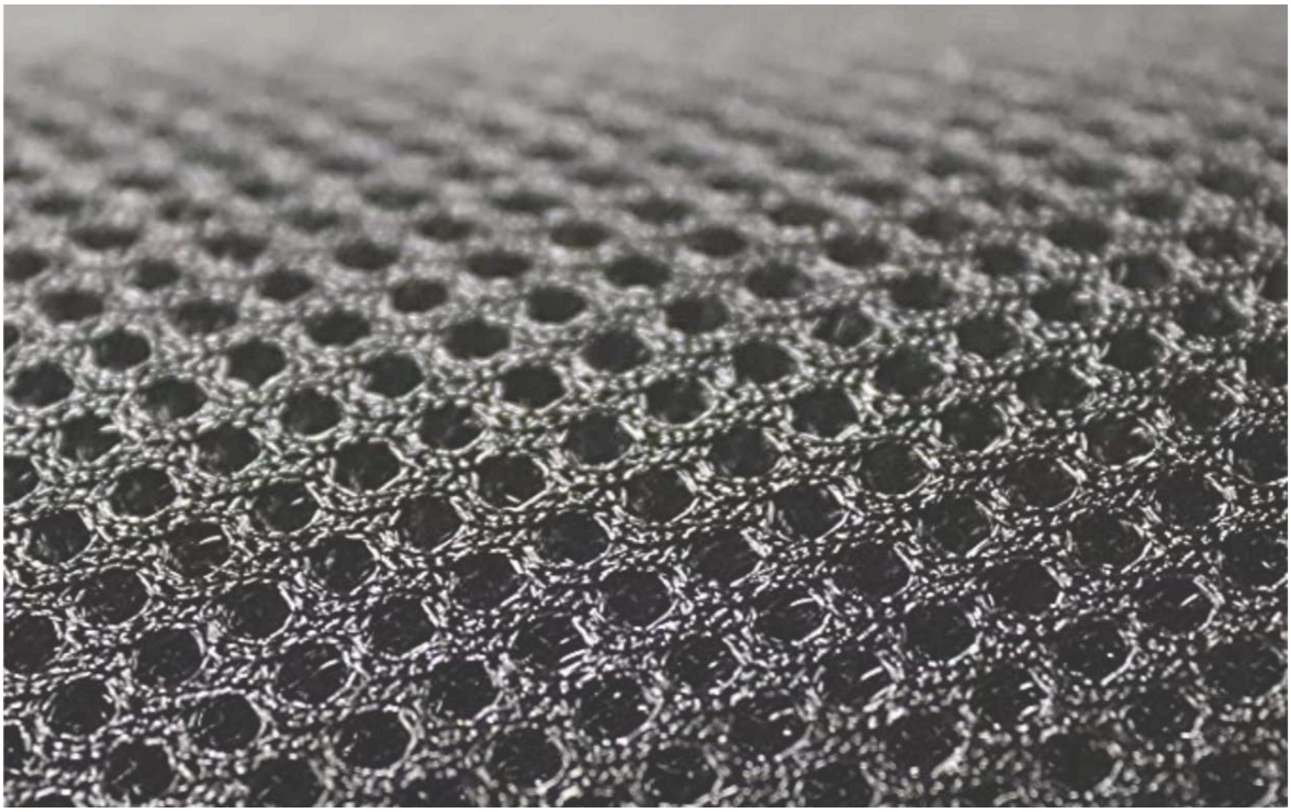


Figure 56: Textile mesh which acts as a cushion

8.4 AESTHETICS DESIGN

COLOURS

In the introduction of this project, the fashion industry has been mentioned. An industry in which the feeling of individuality creates certain demand for products because of their aesthetics rather than their functionality. For this reason, this aspect of the solar collar is highlighted again in order to respond to this demand for certain aesthetics. Doing this should benefit the desirability of this project's final product.

Colours can evoke a variety of emotions due to their psychological effect (Solar, 2018). The product is made as a hybrid version of a collar and a necklace which also should be part of an outfit. In order to make the product less obtrusive in its design with the clothing, the colours should be chosen strategically.

One of the most influential businesses which focus on colour consistency across various materials and finishes for graphics, fashion and product design is Pantone. "For over 20 years, Pantone's colour of the Year has influenced product development and purchasing decisions in multiple industries, including fashion, home furnishings, and industrial design, as well as product packaging and graphic design." (Pantone, n.d.). The colour of the year is done through trend analysis. For this reason, the colour can differentiate significantly without having a certain relation to the previous colour of the year.

Figure 57: Pantone's colour of the year

As the solar collar needs to feel like a part of the user's outfit the product needs to work well with what the fashion industry is producing. Carla Solà, professional visual merchandiser, fashion stylist and creative content creator has been contacted. She is hired by people needing a fashion stylist or for physical stores where the composition of certain pieces have the effect that the items on the mannequins sell fast. To boost the sales this is done every two weeks.

She suggested using the colour dressing guide. This guide is a basic visual guide initiated by stylists with certain colour combinations that work well with each other.

According to this guide the colours that work well with most colours are the shades of black, white, and dark/light blue. For these reasons the available colours of the solar collar need to be one of these colours as these seem to be the ones which work well with most of the other colours.

CONCLUSION:

The colours best suited for the collar are black, white, and blue. These colors seem to fit best with other colours that are used by the fashion industry's changing trend colours.

Figure 58: Colour dressing guide

MATERIALS

While the impact of colours on can make a significant change in the aesthetics of the product the textures do too. The variability of textures of the solar collar are restricted as it should remain to be comfortable enough to wear around the neck.

The inner part against the skin of the neck needs to be comfortable, soft and flexible. Textile mesh has been chosen for the initial design of the solar collar while more materials are possible. Polyester fabrics are known for their flexibility and therefore are well suited for the solar collar. Another benefit of the material is the possible diversity in textures that could change the aesthetics significantly to apply to the individual's taste.

Figure 59: different textiles can be used for the inside of the Solar collar

Figure 60: Yves Saint Laurent turtle leather on their product

The outer layer of the solar collar also shows great potential for customization in terms of texture. The layer on which the solar cells are placed could be made by boss-extruding certain patterns. Doing this a certain premium leather look could be mimicked.

For example the structure of this leather from Yves Saint Laurent's product is from the special turtle leather collection. According to store director René Hol at YSL in Rotterdam the leather is not from actual turtles as this would be unethical given the current population and their vulnerability. René stated that the leather was pressed with a pattern in order to simulate the turtle scales on the leather.

This same principle could be used for the flexible solar cells. By creating patterns by utilizing height differences the solar panels can be made to form certain patterns that enhance the aesthetic of the solar collar.

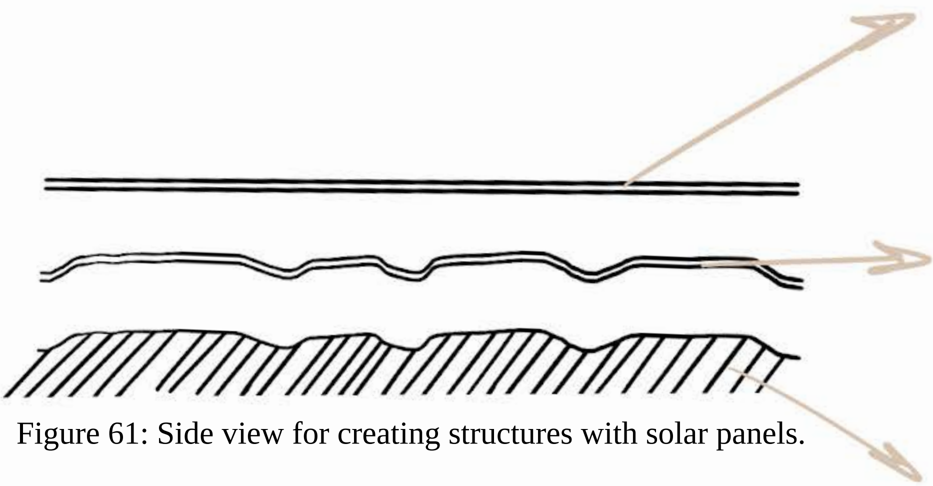
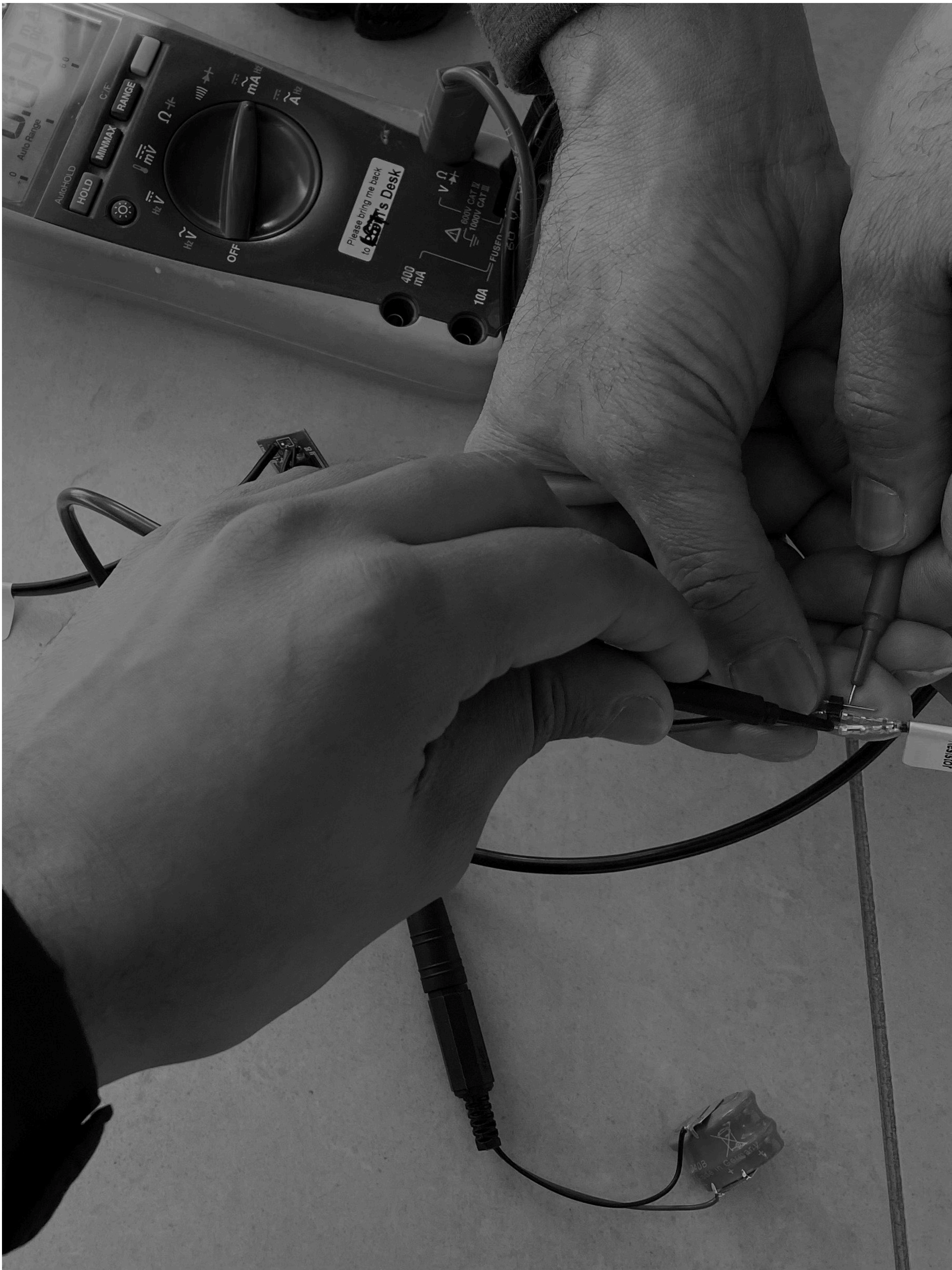


Figure 61: Side view for creating structures with solar panels.

9. FINAL WORDS

Last words about the most exciting project I have ever worked on as a design engineering student.



HOLD
MINMAX
RANGE
Auto Range
AutoHOLD
OFF
Please bring me back
400 mA
10A
FUSED
600V CAT III
1000V CAT II

Before the project started, the incentive for me as a design engineer was to have a project topic that further focuses on the possibilities for the fashion industry and the development of smart clothing. At the start of the project, I decided to “grab” this project and make it personal after my grandmother fell in her home. At these moments time is crucial and to make sure the biosensor would work without depending on the battery alone. Combining this personal situation and my field of interest brought me a project which I liked the most to finish my study years with.

While this project is focused on the elderly, this project has more potential for the future. The use of a biosensor is not restricted to old people but could also be used for the masses and people with diabetes or younger people playing sports. These people could also want to have their parameters measured when participating in certain activities. If the solar collar is made for these people too we might leverage on demands from different consumer markets.

In the introduction, the topic of sustainability has been mentioned to also be a driver for this project. The final product is able to convert energy and direct it to a biosensor. While this project is focused on the functionality of the biosensor, the future might have more options for the solar collar.

As the development of smart clothing continues, the Solar collar could be part of this innovation. Smart clothing can be dependent on electricity which initiates a certain change of the piece of garment. The development of energy-demanding pieces of clothing can be observed by many fashion brands nowadays. Instead of depending on external batteries, the needed electricity could be won with a local energy harvesting product that can be worn with the outfit too.

The development of the solar collar could therefore help towards a future in which we are less dependent on the use of small disposable batteries and possibly create awareness in the way we demand energy.

Figure 62: Louis Vuitton bag with embedded OLED screen that requires electricity to function

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APPENDIX

APPENDIX 1

DESIGN FOR our future

TUDelft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Gaya

initials: V.M. given name: Vinay

student number: 4357345

street & no.:

zipcode & city:

country:

phone:

email:

Your master programme (only select the options that apply to you):

IDE master(s): ★ IPD ( ) DfI ( ) SPD

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: ( ) Honours Programme Master

specialisation / annotation: ( ) Medisign

( ) Tech. in Sustainable Design

( ) Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Prof. dr. ir. Janssen — dept. / section: SDE - EM

** mentor: Ir. Klein — dept. / section: SDE- CPD

2nd mentor:

organisation:

city: — country:

comments (optional):

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

Procedural Checks - IDE Master Graduation

TUDelft

APPROVAL PROJECT BRIEF
To be filled in by the chair of the supervisory team.

chair Prof. dr. ir. Janssen date 12-10-2020 signature

CHECK STUDY PROGRESS
To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: _______ EC

Of which, taking the conditional requirements into account, can be part of the exam programme _______ EC

List of electives obtained before the third semester without approval of the BoE

YES all 1st year master courses passed

NO missing 1st year master courses are:

name ________ date - - signature ________

FORMAL APPROVAL GRADUATION PROJECT
To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name ________ date - - signature ________

Initials & Name V.M. Gaya Student number 4357345

Title of Project Design of a modular system for energy harvesting

Personal Project Brief - IDE Master Graduation

TUDelft

Design of a modular system for energy harvesting

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 28 09. 2020

12 03. 2021 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

This project is focussing on the innovation of clothing. The "technology industry" and the fashion industry need to work together in order to make the innovation of clothing succesfull (Ariyatum & Holland, 2003). As a result it is expected that clothing will change overtime. Examples of these changes may be the embedding of electrical components and possible requirement of more energy.

The development of modular systems for the innovation of clothing offer various benefits. The user is free to customize the function of their clothing and this modular elements add to the durability of this innovation. Being able to replace one element when there is a defect is a more efficient solution for the user and the environment.

In order add to these two developments my thesis will be focussing on the energy harvesting possibilities with the use of a modular system. Due to the rising demand for energy the harvesting of energy gets more interesting. An efficient way to do so is going to be reached in this thesis.

the stakeholders for this project are the researchers that have a similar focus on the development of this technology. These researches could be interested in the final result of this project and could make significant iterations to further develop this technology. As the development of smart clothing is ongoing the rise of energy for these extensive functions of clothing are also increasing. Creating an alternative for the heavy batteries that need to be charged every time allows for a more holistic design of smart clothing which can generate the energy they need to function. In this sense all researchers working on the development of smart clothing could be considered a stakeholder of this project.
Lastly businesses that would like to further develop this technology to commercially exploit them will also be interested in the development of this technology thus this project.

Main opportunities for the focus of this project may be that we identify another source of energy which was not yet efficiently used (like the movement of a person over the timespan of an entire day).
Limitations are that of the current developments and the ongoing development of smart clothing in general. If demand for smart clothing will never rise the development of this technology and that of smart clothing in general will be "in vain".

space available for images / figures on next page

introduction (continued): space for images

In one of the shows off Louis Vuitton they showcased a bag in which an Oled screen was implemented. This combination of technology and fashion is likely to take of in several years as the possibilities with this combination are endless but the concept seems relatively easy to adapt for the consumers. This combination of Oled and fashion has also been done with LV sneakers in the same exact show. If there was a way of providing these innovations with sustainable energy (like the mechanisms of a dynamo) the current energy demand will not rise for this change.

image / figure 1:

Figure 2 shows a mechanism that has inspired me throughout the years. It was the ability to generate energy "without any effort". The watch was already being moved throughout the day which was the perfect opportunity to generate energy for the watch itself to work on. Having a similar mechanism embedded in clothing for the use of smart clothing seems like a promising application. This was the reason for initiating this project.

image / figure 2:

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

In order to make the development of smart clothing successful the lack of technical knowledge form one of the barriers (Ariyatum & Holland, 2003). When focussing on this fact and the rise of the energy demand the topic of this research reacts on both facts and aims to come with a solution.

The focus for this project is on the possibility to integrate a modular system for energy harvesting. Creating this system allows for an easier adoption of these energy harvesting elements in clothing. This project should ook into the best alternative to harvest energy and should eventually design a system in which is modular. This modular system adds value in terms of sustainability and durability.

Manageable for this project is come up with at least a physical and virtual prototype of the system that we aim to design. The different possibilities for energy harvesting should be considered an evaluated when implementing in textile.

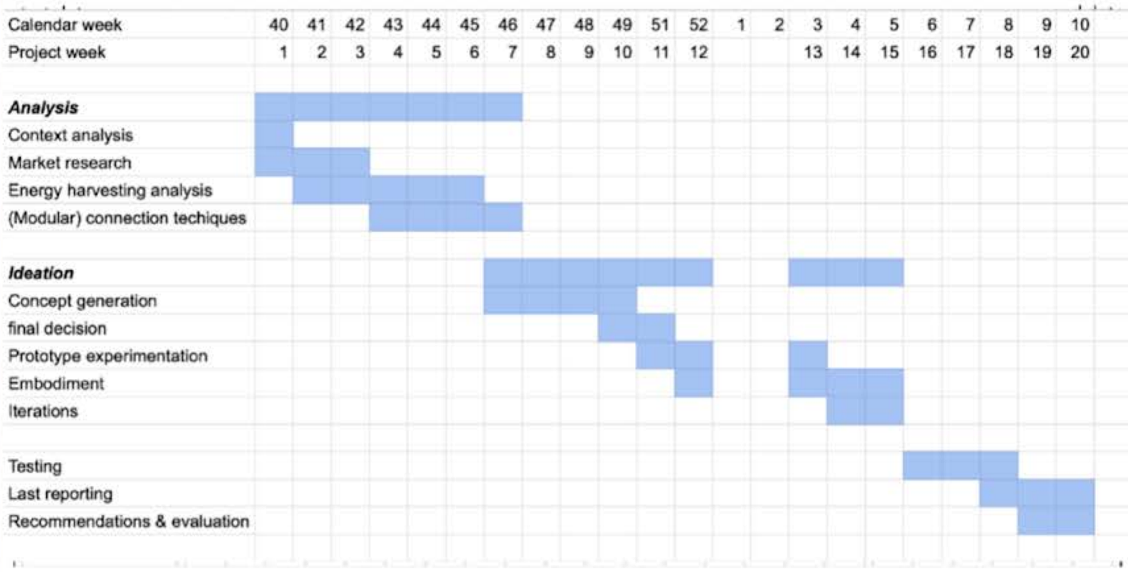
ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

For this project the aim is to design a modular system that is capable to integrate energy harvesting into clothing. This design should be both physical and virtual and recommendations should be given for possible iterations.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.



For the approach of this project the time planning has been done as shown above in the Gantt chart. Focus on both the ideation and the possibilities for prototyping has been integrated in this project. This choice has been made as I would like to test my skills in conceptualization and prototyping. Also do I think that both "conceptualization" and "prototyping" are skills of Design Engineering that an IPD student should master.

The time which has been reserved for this project also includes a two-week break for the Christmas Holidays in order to take some rest in between the work and allow to reflect on the work I have done so far. This might help me further structuring the work I have to do after the holidays towards the deadline. The focus then lies more on experimenting and testing with the physical prototype. Also lastly finalizing this project will consist of iterations, recommendations and evaluation of how the final product of this project could be improved in the future.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

The topic for this project has been chosen due to my personal interest in sustainability and smart clothing. Being able to combine these two and potentially add to the development of smart clothing development would be one which I would love to graduate with. As my personal goal is to eventually be able to provide smart clothing to the bigger market and change the way people look at (fast)fashion and be more considerate. When clothing is more than only the aesthetics this goal of the perception change might be feasible. The impact of energy harvesting features may be underestimated. We "waste" a lot of energy since we consume but with not taking advantage of the power of our mobility enough. I would love to identify the possibilities to do so and making this system modular such that it will be adaptable for other researchers' projects like Prof. dr. Ir. Janssen.

In this project I would like to prove that I'm worthy of a MSc. title with the capacities I have learned over the years of this master. I would like to prove my skills of working with fabrics due to the smart jackets that my teams and I were able to produce in the AED course and take it to the next level.

In this project I would love to learn more about the possibilities with smart clothing and take one step further than my last smart jacket. As mentioned earlier I would love to do something with smart clothing later but for this concept to be market ready a lot has still to be done. Taking on this challenge will bring me one step closer to my dream of being able to add to the development fo smart clothing in general.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

APPENDIX 2

Aesthetics evaluation with target group

For the evaluation of the concept one factor would be the aesthetics. While this may differ from person to person the different concepts are proposed to the target group of this project. For this evaluation 15 participants were asked to take part of this survey.

When presenting the design directions the interviewees were asked to give each of the proposed directions a score. In order to make this score compatible with the harris profile they were asked to give them one of the following scores: -2, -1, +1 or +2. The average score of these three directions will be taken into account for the evaluation with the Harris Profile in chapter 5.3.

Participant #	Hybrid solar vest	Solar Collar	Solar Scarf
1	1	2	2
2	2	1	1
3	-1	1	1
4	1	1	1
5	-1	-1	2
6	1	2	1
7	1	-1	2
8	-2	1	1
9	1	1	-1
10	-1	2	1
11	1	1	1
12	1	1	2
13	2	2	1
14	1	-1	2
15	1	1	1
Average score	0,533333333333333	0,875	1,1875

APPENDIX 3

Iterative form finding

In order to create iterations on the designs of the solar collar every model that was made was proposed to 5 people of the target group. When showing the prototype these people could give feedback to what extent they liked certain features and how certain elements needed to be improved to create a product with better perceived comfort.

Model 1

Participant #	Positive feedback	Negative feedback
1	Simple form	Too wide but has to do with the person.
2	Universal for both men and women	Seems too thin and fragile
3	Not too obtrusive	Too big and does not follow the shoulder’s form
4	Looks nice and universal	Should be more comfortable
5	-	Too thin and feels too static around the neck

Conclusion

The first model needs to be made smaller. The orifice in the product for the neck seemed to be too big. The product needs to be more comfortable around the neck as it feels too static.

Model 2

For this model the size of the orifice for the neck has been reduced and it was made to follow the shoulders better. The bottom part of the product has been made with “cutouts” of where the shoulders would come. Also did the back of the product have a thicker part in which the electrical components like the battery could be implemented. This would also function to follow the back of the neck.

Participant #	Positive feedback	Negative feedback
1	Looks more subtle and fits better than the last one	Looks a bit too fragile now
2	Looks nice with the form that follows the neck and shoulders more	Seems even more fragile
3	Follows the form of the shoulders a little better but not quite much	A bit too close to the neck. Does not follow body enough to be comfortable
4	Looks more comfortable	The font two points are a bit too much in the way
5	Looks more dynamic	Not dynamic enough around the neck and shoulders

Conclusion

The curvier design on the bottom of the model seemed to be working well for how it would rest on the shoulders and around the neck. The dynamic form was working well but could be made even more curved to follow the neck and shoulders better. Also the product should be made in a more study way such that it does not look as fragile.

Model 3

This model was made thicker and with a bigger orifice for the neck. Also was the product given a more dynamic form by letting it follow the shoulders better. Instead of using a “cut out” for the shoulders the entire product is bent to the font and the back. The back part which was thicker and followed the beck was made less wide.

Participant #	Positive feedback	Negative feedback
1	Looks more robust	Too wide
2	Follows shoulders and neck well	Too wide and the thicker part in the neck should be less pointy.
3	More robust and dynamic form	Front should be more directed to the chest
4	Follows the shoulders better	Front should be more down to make it more dynamic
5	Dynamic forms	Looks too big

Conclusion

This model seems to be too bulky and wide. The curvy design does work well according to the feedback. The back part, where the band is thicker, is not appreciated. Feedback shows the design should be less “pointy”. Also the front part should be made to face towards the chest even more.

Model 4

For this model the front part was made to be flatter instead of pointy. The cutout has been made again as no clear comment was made about this feature in the last model. The orifice for the neck was made smaller again similar to that of model 2 but this model has more “body” which makes it less fragile. Also was the thicker part on the back made wider after a comment was made on this part of the design.

Participant #	Positive feedback	Negative feedback
1	Follows chest better	Top part could be curved too
2	Fits well and has a nice form	-
3	Nice form and curved to the front	Can feel the item sitting in the neck as it limits the neck movement.
4	Nice design with the flatter front parts	Could be flatter at the front
5	Fits nicely	Could be curved more

Conclusion

The front parts curve more towards the chest area which makes an even better design in terms of comfort. The design however could be curved more in order to be more comfortable.

Model 5

Compared to the previous model this one has been given more curve in its entirety to be bent more to the chest and to the back. The orifice for the neck and other dimensions have been kept the same.

Participant #	Positive feedback	Negative feedback
1	Curved nicely	-
2	Fits well	-
3	Curves of the product make it more comfortable	-
4	Good design with more curve	-
5	Follows the shoulders even better.	Could be made thinner and softer

Conclusion

As this model is rather similar to model 4 this model is a bit more curved. The top part around the neck is also curved. Both the back and the front side are more bent toward the chest and the back. This adjustment took away the earlier comment about the solar collar being limiting on the possible movements with the neck. The new design curves better with the shoulders so that the collar takes less space in the height around the neck.